foundation material to be built upon is solid rock, into which the piles cannot be driven, a problem of a very different nature is presented. In such a case the excavation inside the cofferdam has to be carried down to, or even below, the level on which the pointed piles themselves rest, so that, when the outside head of water is considerable, and the surface of the underlying natural rock is exceedingly uneven and irregular, it becomes a most difficult matter to exclude the water and sand, and prevent it rushing in between the bottom of the cofferdam and the surface of the rock. During the interval necessary for the work of levelling the rock surface and building up the masonry to a height sufficient to enable the lower part of the dam to be securely stopped from the inside, the rise of water can only be kept down by an extraordinary application of pumping-power sufficient to cope with the inrush, which, in spite of all expedients that may be employed, such as the sinking of bags of clay or cement around the feet of the piles, must always be exceedingly heavy.

If the pressure or head of water to be excluded is small, a single cofferdam can be made sufficiently water-tight; but beyond a certain depth it is necessary to employ a *double* dam, that is, two lines of piling, one inside the other, with an interval usually about 6 or 8 feet between them. In this case the space between the two rows of piles is first excavated as far down as possible by the aid of pumping-power, and bags of clay are then carefully packed and piled within it. These bags by their own weight, and by the weight of other bags continually added from above, gradually sink in proportion as the sand below them is forced into the interior of the now excavated dam by the underflow of the water, until eventually they reach the rock surface, and serve materially to reduce the rate of inflow through and underneath the piling, thus enabling the pumps more easily to cope with the volume of water, until at last the whole interior area of the cofferdam is laid dry, and the workmen are enabled to level the surface of the rock, in readiness to receive the first foundation masonry.

It was by the above means that the foundations of the greater number of the piers, and the large and deeply-founded southern abutment of the Kanhan bridge was laid on the rock

bottom of the river-bed. In this work, including wet and dry excavation, about 3 millions of cubic feet, or 130,000 cubic yards of material, weighing upwards of 187,000 tons were excavated, of which more than half a million of cubic feet was excavated below water-level at the site of one foundation alone, viz., in reaching the rock under the southern abutment of the bridge, where the size of the double cofferdam employed was 180 feet long and 60 feet broad. The double cofferdams at the sites of the deepest piers were 80 feet long and 43 feet broad, the depth of the rock below sand and water-level being from 15 to about 27 feet. Nearly 20,000 cubic feet of timber and 18 tons of manufactured ironwork were utilised in the construction of these foundation cofferdams.

The piers and abutments of the bridge are built of rock-faced ashlar, hearted with rubble masonry of a substantial character. The piers are 10 feet in thickness at the top, increasing downwards, according to a batter or inclination of 1 in 24. The twelve spans of the bridge are divided into three bays, or series of four spans each, by abutment piers of heavier dimensions, it having been intended in the first instance to construct the arches in sets of four. Subsequent arrangements, however, by means of which the timber centerings, or supports on which the arches were built, were enabled to be left standing during the flood seasons, permitted the arches to be constructed independently of the abutment piers. Four sets of timber centres for the temporary support of the arches during construction were, however, employed. These were constructed chiefly of foot square timber, disposed according to a very firm and rigid design. During the turning of the archwork, each centre had to support a maximum dead weight of 570 tons, and owing to the very flat form of the arches it was absolutely necessary that the sinkage or settlement of the temporary timber work under this great weight should be as small as possible. That the design fully answered the requirements of the case is evidenced by the circumstance that the maximum subsidence of the centres under the 570 tons of dead weight imposed upon them was hardly more than 2 inches.

In the case of every span where it was necessary that the centering should remain standing during the rainy or flood

velocity said to approach 11 miles an hour. Just above each canal head a lock and channel for the navigation is constructed in the river bank.

The main canals taken off for the supply of the eastern and western portions of the delta are 200 and 230 feet wide respectively, each carrying a maximum depth of water of 8 feet. The Kistna delta canals have a total length of main line and branches of 325 miles, of which 284 miles are navigable. There are also 1614 miles of distributing channels, commanding over 800,000 acres. In the year 1890-91 the value of irrigated crops raised was £1,123,705. The system like that of the Godavery and other delta irrigation works in Madras is exceedingly remunerative.

Pennair Delta Canals.

The delta of the river Pennair has a very much smaller area than either the Godavery or Kistna. An *anicut* across the river at Nellore was first proposed in 1849, and it was completed in 1855, but was a few years after partially destroyed during a furious storm. It was restored, and again completed in 1861. In the year 1871 it was lengthened to its present dimensions. The *anicut*, which is now 2031 feet long, crosses the Pennair close to the town of Nellore, and a system of canals having 142 miles in length of main line and distributaries, is derived from above the weir on its right flank, and provides irrigation on the south side of the river. The water supply, which is very precarious, is supplemented by storage from the Nellore and other tanks.

Sangam Irrigation.

Subsequently, in 1886, a second weir, 4076 feet long, and 12 feet high, was constructed across the river about 17 miles higher up, opposite Sangam, for the supply of irrigation to the tracts lying to the north of the Pennair. Two main canals taken off above the Sangam weir lead the water into several large reservoirs, and the irrigation of the district is supplemented by water stored in numerous other tanks. There are in all 259 miles of main line and distributaries connected with the Sangam irrigation. The combined area irrigated on the north and south sides of the Pennair delta is about 133,000 acres.

Srivaikuntham Canals.

In the extreme southern part of the Peninsula the Tambrapurni river flows into the sea a few miles south of Tuticorin in

treacherous nature of the subsoil of the Ganges valley as a foundation for arched structures was moreover at first imperfectly realised, and much reconstruction and replacement of brick arches by iron girders, was from time to time rendered necessary.

Leaving the Province of Bengal, the line of the East Indian Railway proceeds to Moghul Serai, a junction station for Benares, and to Allahabad, where it crosses the Jumna river by a magnificent bridge, and throws off a long branch to the Jubbulpore terminus of the line from Bombay. From Allahabad the main road is carried in nearly a straight line to Cawnpore (finally leaving the neighbourhood of the Ganges at that place) and across the Ganges Jumna Doab to a point within thirteen miles of Agra, to which town a branch line now extends. Hence by the left bank of the Jumna the line is carried to Delhi, where it crosses to the right bank of the river and enters the city. Excluding the recently erected bridge over the Hooghly channel near Calcutta, the four principal bridges on the original main line of the East Indian Railway are those over the Sone river, the Tonse, the Jumna at Allahabad, and the same river again at Delhi. The first and last two of these bridges are remarkably fine structures, and are only dwarfed by a few more modern examples of bridgework situated on other lines.

The bridge over the Sone river merits somewhat detailed notice, as the first example of those large iron railway bridges now so numerous in India. It was begun in the year 1856, and was finished at the close of the year 1862, its progress having been seriously interrupted by the Sepoy Mutiny of 1857. The total length of this fine structure is 4731 feet or $\frac{7}{8}$ths of a mile, and it consists of 28 decked spans of 150 feet, or 162 feet from centre to centre of piers, which are each 12 feet thick, carried on three brick wells of 18 feet diameter, sunk to a depth of 32 feet below low-water into a stiff bed of yellow clay. The following account of this interesting bridge is much abridged from a work on the railways of India, compiled from the Records of the India Office, and published in the year 1868 by Captain Davidson, R.E.—a work to which this volume is greatly indebted for much information on the earlier railway

finished off with a rough stone plinth, on which, on a slightly smaller sectional plan, the upper pier work was built up in solid brickwork to the necessary height of $72\frac{1}{2}$ feet above low water level, each pier being finished off with a handsome terminal cornice.

The nine smaller piers for the extension spans were founded on two $12\frac{1}{2}$-feet wells, with iron curbs, pitched 25 feet apart from centre to centre, sunk from 67 to 157 feet below ground-level by means of dredgers. At 5 feet above low-water level the two wells were connected by a corbelled arch, and the solid piers were then erected on the top. These piers are 35 feet long, and 10 feet wide, with parallel sides and semicircular ends. The total quantity of brickwork in the Dufferin Bridge is 1,876,289 cubic feet, or 69,492 cubic yards, and the cost of the main piers was Rs. 7,57,988, or an average of Rs. 1,08,284 per pier, sunk to an average depth of 102 feet below low water.

The main girders of the bridge were erected in place on a staging and platform formed by utilising the 114-feet-span girders afterwards used in the extension spans. Three pairs of these girders were supported in each larger span on two intermediate temporary piers, formed by clusters of twelve 6-inch solid iron screw piles, pitched 10 feet apart, well braced together, and connected at the top by steel-plate girders; the extension girders intended to carry the weight of the main spans in course of erection being temporarily strutted and strengthened to the necessary extent. Some difficulty occurred in erecting the temporary piers in the deep-water spans, where the screw piles had to be fixed in 65 feet of water. Artificial mounds or islands of sand, supported by walls of sand-bags, were here formed to give lateral support to the lower portion of the piling, and the temporary structures were stiffened by steel-wire guys or ropes, secured to anchors up and down stream. The main girders were erected, piece by piece, by the aid of travelling gantrys or overhead cranes, carried by the staging; they were set to a *camber*, or rise in the centre, of 9 inches, which was reduced to 6 inches on the supports being removed, and to $4\frac{1}{2}$ inches under the full load of the roadway.

The riveting together of the steel-work of the huge girders was almost entirely done by hydraulic riveters, and as the main

WAYS AND WORKS IN INDIA

daily supply of water was 2,500,000 gallons, or 25 gallons per head per day for a population of 100,000 persons. The rates charged for private supplies, after the opening of the works, varied from 5 to 1 Rs. per month, according to size of connection, or from 6 to 10 annas per 1000 gallons by meter. As the water flows by gravity from the supply-wells to the distributing reservoir, there is no expense for pumping; whilst the cost of maintenance, repairs, and establishments is at a minimum. The scheme, therefore, should be a remunerative one to the inhabitants and municipality. The Karachi Waterworks were formally opened to the public on the 21st April 1883, but were not fully completed until the year 1884.

'It will perhaps be as well to distinguish three species and degrees of ambition. First, that of men who are anxious to enlarge their own power in their country, which is a vulgar and degenerate kind; next, that of men who strive to enlarge the power and empire of their country over mankind, which is more dignified but not less covetous; but if one were to endeavour to renew and enlarge the power and empire of mankind in general over the universe, such ambition (if it may be so termed) is both more sound and more noble than the other two. Now the empire of man over things is founded on the arts and sciences alone, for nature is only to be commanded by obeying her.'—BACON, *Novum Organum*, cxxix.

CHAPTER V

JUBBULPORE—CONCLUSION

Jubbulpore Waterworks—Scarcity and impurity of the former water-supply—Population of Jubbulpore—Outline history of the scheme—Main features of proposed works—Provision of funds—Preliminary operations—Construction of the masonry dam—Escape weirs—Straining and regulating tower—Pipes, valves, and supply main—Arrangements for future extension of the water-supply—Concluding observations—Other water-supply projects—Water-supply of Lucknow—Artesian well—Failure to obtain water—New scheme—Outline of project—Water-supply of Delhi—Conclusion.

Jubbulpore Waterworks, 1881 *to* 1884

A very thorough and well-considered scheme of water-supply for the provincial city of Jubbulpore, in the Central Provinces, was carried out between the years 1881-1884. This rapidly rising city and important railway centre, previous to the construction of the water-supply works now to be outlined, was dependent on the supply afforded by numerous shallow wells, for the most part sunk in the hard granitic rock with which Jubbulpore abounds. The water derived from these wells, at the best of times, was uncertain in quantity and of indifferent quality; but in years of short rainfall it was extremely scanty and impure. By the census of 1881, the population of the native city and military cantonments of Jubbulpore numbered nearly 63,000. In the city proper, numbering about 47,500 souls, there existed 1058 wells; but less than 200 of these furnished water suitable for drinking purposes, and even in years of average rainfall a large proportion of the latter ran dry.

In the year 1874, the scarcity of water was so great that it sold in the city at from 2 to 4 annas per *ghurra* (a vessel holding about 2 gallons); and this is stated to have been a customary experience in the hot season, except after years of heavy rainfall. A large number of the wells in the city were

WAYS AND WORKS IN
INDIA

BEING AN ACCOUNT OF
the Public Works in that Country from
the Earliest Times up to the
Present Day, by

G. W. MACGEORGE, M.I.C.E.

LATE OFFICIATING CONSULTING ENGINEER TO THE
GOVERNMENT OF INDIA FOR RAILWAYS

WITH NUMEROUS ILLUSTRATIONS AND MAPS

Westminster
ARCHIBALD CONSTABLE AND COMPANY
PUBLISHERS TO THE INDIA OFFICE
14 PARLIAMENT STREET, S.W.

MDCCCXCIV

Edinburgh: T. and A. CONSTABLE, Printers to Her Majesty

AUTHOR'S PREFACE

Materials for the facts and figures grouped together in this work have been mainly gathered from such official publications and Government records as are readily accessible to a writer in England, as well as from numerous published volumes or reports, dealing with separate branches of Indian Public Works, or Indian and English Engineering, and (by kind permission) from many descriptive papers on Indian subjects read at various times before the Institution of Civil Engineers. Where distinct verbal quotations have been made they are indicated by the footnotes or otherwise, but frequently where the general substance of passages, or of statistics, has been paraphrased and condensed, it has not been deemed necessary to burden the volume with constant references.

With regard to the spelling of Indian names and terms, it is feared that some unintentional deviations from the orthodox system may be found. The popular spelling of names of important and well-known places has, of course, been adhered to, and with respect to the remainder, the indulgence of those desiring severe accuracy in this matter is craved.

A precise and detailed history of Indian Public Works is a subject that would amply repay the time and labour spent on its production. The present work barely indicates even the outline of such a history, and has a far humbler and less ambitious aim. It is hoped, however, that the data contained in it may be of some service, as well as interest to the unprofessional reader, as bringing before him in a collected form much scattered information of a kind valuable to all those interested in the progress of India. Some of the principal books, reports,

and other publications consulted and freely made use of are the following:—

Memoirs of Indian Surveys, by Clements R. Markham (1878).
Memoirs of Indian Surveys, by E. C. D. Black (1892).
General Reports of Operations, Survey of India. Thuillier, R.E.
Moral and Material Progress Report, 1872-73. Parliamentary Paper.
The Finances and Public Works of India, 1869-81. Sir John Strachey.
Ganges Canal. Sir Proby Cautley.
Irrigation Works of India. Buckley.
India, by F. C. Danvers.
Lectures on Irrigation Works of India. Rundall, R.E.
Lectures on Water-supply, Rainfall, etc., by Alex. R. Binnie, M.I.C.E.
Roorkee Treatise, and Professional Papers on Indian Engineering.
The Railways of India. Capt. E. Davidson, R.E.
Lecture on Bridges in the Bengal Presidency, by Sir Bradford Leslie, C.S.I., M.I.C.E.
Railway Appliances. John Wolfe Barry, M.I.C.E. (1878).
The Working and Management of an English Railway. Geo. Findlay (1891).
Our Iron Roads. F. S. Williams.
Numerous Papers from *Proceedings of Institution of Civil Engineers.*
Official Publications, Departmental Administration Reports, etc., etc.

G. W. MACGEORGE.

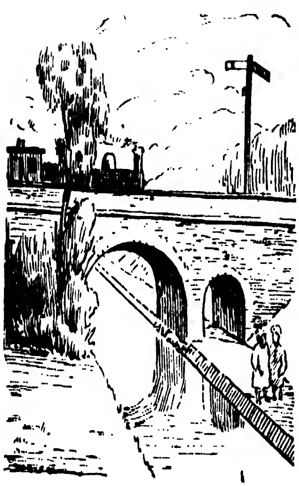
MAIDENHEAD, 1894.

CONTENTS

LIST OF FULL-PAGE ILLUSTRATIONS

The Maps are bound in at the end of the volume.

INTRODUCTION



HERE still lingers in the mind of the present generation of Anglo-Indians an old saying to the effect that if the English were to retire from, or be driven out of India to-morrow, they would leave as the only monument of their rule in that country 'The Grand Trunk Road, and a pyramid of empty beer bottles.' It need hardly be said that this satirical dictum, like many another which was once, perhaps, just pointed enough to prick, has long since lost all semblance of epigram. At the present day no instructed person acquainted with modern India would hesitate to assert that in the whole history of governments—not excluding that of ancient Rome—no alien ruling nation has ever stamped on the face of a country more enduring material monuments of its activity than England has done, and is doing, in her great Indian dependency. Not only has she covered the face of British India with a mileage of roads, railways, telegraphs, and irrigation canals, which, bearing in mind the vast area of the country, and the financial difficulties encountered, may be truly designated stupendous, but the total number of individual works of exceptional magnitude and importance comprised in the whole, probably surpasses that to be found in any equal continuous area in any other part of the world. Other works of public utility, such as water-supply, and drainage of towns, docks, harbours, breakwaters, lighthouses, and public buildings of all kinds, although in number as yet very

far from adequate to the wants of the country, form, nevertheless, a contribution of no mean proportions to that sum-total of constructive energy, which cannot fail to leave the English name for ever indelibly imprinted on the soil of India.

In the following pages it is attempted—it is feared very imperfectly—to bring together, and rapidly sketch in as far as possible untechnical language, and in a form suited to the general reader, some of the more prominent and important public works which have been carried out in India, either by the direct or indirect agency of the Government of the country since the British occupation; and in order that the unprofessional reader may intelligently follow the necessarily very condensed account of these works, a few observations on such general principles of construction as may be needful have from time to time been introduced. It has, at the same time, been sought to convey an approximate idea of the enormous value and extent of each of the separate classes of Indian Public Works regarded as a whole.

It is obvious that such a work can only be of limited interest to the ordinary English public—outside that numerous body of persons, who in one manner or another have identified themselves with the progress and welfare of India—and none whatever to the professional engineer. To the former the subject is too remote, and to the latter the manner of treatment will be found insufficient. To the Indian engineer, although of no practical professional value, the work may possibly supply, in a convenient form, some historical or other data in connection with public works of more or less interest or utility. To the numerous body of general readers, both English and native in India, it is believed that the present volume may afford some useful and interesting information on subjects with which they are partially familiar, and with which they are brought into more or less frequent contact; and it is especially hoped that its perusal by that already large and intelligent class of natives of the country, which the spread of education has so greatly developed, may create in them a wider and more practical interest in what so intimately concerns the social and industrial progress of the people, and that it may help to instil a more cordial recognition and estimation, of the persevering

labour and skill of all those of their fellow-subjects, whether administrative officers, engineers, artisans, or labourers, whether English or native, by whose joint exertions the great public works of India have been and are being carried out.

Wherever it has been possible, attention has been directed to those works of public utility, which in the various Provinces of India have been constructed by native agency, long before the advent of British power in the country. The magnificent Mohammedan or Hindu creations, in the shape of mosques, temples, tombs, and palaces of emperors or nobles, great as many of these are, both as scientific constructions and as artistic monuments to the skill and refinement of their builders, are of necessity excluded; the scope of the volume being confined to those engineering works of general usefulness which bear directly upon the material progress of the people. In this special branch of utilitarian energy the modern Western nations stand pre-eminent, whilst they have to a great degree lost proficiency in those more graceful arts in which at an earlier period they also excelled. If we adequately picture to ourselves what was the material condition of the most advanced countries of the West hardly more than a hundred years ago, we shall not feel surprise if we find in India but few examples of those large engineering public works, which in every part of the world so eminently characterises the modern era. The political condition of the country for ages rendered it next to impossible that works of public improvement should have been attempted; the early history of India presenting an almost continued scene of internal discord, and the numerous and constantly changing divisions of territory between ambitious and despotic rulers, renders it vain to seek for, or expect, evidences of any concerted action for the public welfare. Nevertheless, especially in some of the great ancient irrigation works and reservoirs of Southern India, we shall be able to point out the existence of a very considerable engineering skill and boldness of enterprise possessed by the early Hindu race. No special selection of these works of purely native origin has been made, but such examples as the author has been able to meet with have been indicated. It is more than likely, however, that a large number which it would

have been of interest to have noted have been unintentionally overlooked.

Although the volume deals primarily with important public works of a distinctly constructional character, it has been judged appropriate to devote a little space to an outline description of the operations of the 'Great Indian Trigonometrical Survey,' which stands in the very foremost rank of magnificent human labours. Achieved in the face of impediments, and difficulties, due not only to immense superficial area, and physical obstructions, but also to the deadly effects of a climate that only the strongest can withstand, this great survey has been carried on and brought down to practical completion with unflinching pertinacity and incredible zeal over the long period of some eighty or ninety years, at a most considerable cost to human life, and at a money expenditure only commensurate with the great ends attained. To the Government, as the principal landowner of the country, the Topographical and Revenue Maps, based on the Great Trigonometrical Survey, and produced with so much careful accuracy by the surveyors of India, provide the principal basis on which the whole fiscal adminstration depends. The practical engineer, furnished with so much accurate and valuable data ready to his hand, can proceed to the elaboration and execution of his projects with a certainty and celerity which he could not otherwise attain, and numberless operations in other fields of labour are immensely facilitated. No one acquainted with the splendid series of maps of all classes issued to-day by the Survey Departments of India can fail to acknowledge that the vast operations by means of which these results have been attained forms in itself a monument of which any nation may be proud.

Owing to the almost complete absence of precise returns in any accessible form, it has unfortunately not been possible to outline in an adequate manner, either the early history or present extent of the chief public roads of India, whether in the case of those more important trunk thoroughfares of the first class, which, carried over enormous stretches of country, are metalled, and for the most part bridged throughout their entire length, or those still more numerous roads of secondary import-

ance. Even in the case of that interesting early work known as the 'Grand Trunk Road,' extending 1500 miles from Calcutta to Peshawur, the available information appears to be extremely meagre. The aggregate length of metalled and bridged roads throughout India, constructed by the British Government, must undoubtedly be enormous, but in the absence of any certain figures it would be exceedingly hazardous to attempt even an approximate estimate. During the last thirty or forty years a very large expenditure on common roads and bridges of all classes has been incurred, especially in the Panjab, the Central Provinces, and Bombay, and it is probable that the amount so expended, from general and local funds, has reached little short of a million and a half sterling annually.[1] The necessity for new trunk roads has in great measure been reduced by the rapid extension of railways, and road-making, except in the hills, has for many years been confined to those primarily intended to give access to railway depot; a far greater extension of such feeder roads is, however, still one of the most pressing requirements of the country.

A considerable portion of the volume is devoted to a narrative of the rise and development of the railway system; to the leading features of practical railway construction, and to a description of the larger and more important bridges and other works connected with railways in India. This is but a necessary consequence of the special importance and interest of the subject. Not only may the railways of the country be truly called the vital organs of industry and commerce, and the very mainsprings of material progress, but from their close and intimate connection with the daily life of so large a section of the people, details concerning them are probably capable of affording to the general reader a more certain and connected interest than would be the case with any other form of engineering work. The educated native of India of the present day—of sufficiently mature age—can hardly fail to recognise how greatly the material conditions of his existence have, during the course of his life, been ameliorated, how largely his

[1] Memorandum on some of the results of Indian administration during the past thirty years of British Rule in India.—Parliamentary Paper, 1889.

freedom of action, and possibilities of activity in every direction, have been increased, and to what a surprising extent the general lowering of the cost of production, since the introduction of railways, has developed and stimulated the industrial resources and commercial prosperity of the country. Admitting the considerable social and moral advancement of late years due to education and the spread of Western habits of thought, he cannot, at the same time, fail to perceive that the extraordinary progress, the patent steady advance in the average wealth and culture of the peoples of India, of which, for the last thirty or forty years, he has been the witness, has been originated and alone rendered possible, by the timely introduction and practical application in India of those various arts which have directed 'the great sources of power in Nature to the use and convenience of man'—in other words, in consequence of that enlightened policy of the English governors of the country which—especially during the last thirty years—in spite of financial difficulties and scares of all kinds, has urged them to persevere in the projection, execution, and extension over the length and breadth of India of great public works of every class.

It is outside the scope of the present volume to touch, except in the briefest manner, on the purely financial side of Indian public works; although it will be necessary, in order to represent the true magnitude and importance of many of these undertakings, to exhibit an outline of the general, commercial, and statistical results of their working. Those, and there are still some, who object to the large annual State outlay of borrowed money on works held to be reproductive, deny in the first place their real remunerative character—plead the poverty and inability of the country to pay for what they regard as the luxuries of civilisation, and maintain that the development of the resources of the country is no sufficient warrant for their construction by means of public loans, of which so very small a percentage can be—or at least hitherto has been—raised in India, and the interest on which, remitted by Indian tax-payers to English creditors, constitutes so heavy—and in their opinion so increasing, a burden on the country. No matter at what immediate sacrifice, they believe in a strict adherence to English

precedent, and would relegate all such works to private enterprise; make the confidence of investors the touchstone of remunerative probability, and leave to a speculative public, whether European or native, all profit and responsibility.

It may, however, be urged that the construction on a suitable scale, of railway and other reproductive works in India, by means of money borrowed, or guaranteed by the State, has been, under the conditions of the country, the only means by which such works could have been constructed at all. Nor does it appear that any serious economic objection to such a course can be made, unless at the same time it can be shown that the public burdens are not only temporarily, but permanently increased. A certain period of time must necessarily elapse before either railway or irrigation works become directly profitable, and a reasonable interest charge during such period, represents the price to the country of the enormous indirect benefits in the meantime secured, the direct return being at no time a fair or adequate measure of their real economic value.

There are no grounds for disputing, as a matter of fact, that the most rapid possible extension of canal irrigation and railway communication has been amply justified by the single considerations of famine protection and military necessities, nor can it be seriously disputed that the real financial results of railways, including those large indirect returns from a thousand channels, due to their interaction on the industrial progress and activity of the people—which in a country in the situation of India is of such incalculable importance—has proved them, so far as the balance of public interest is concerned, to have been no less truly reproductive works in the past than they will be in the near future, when they become a large and most important source of direct revenue to the State.

It may be allowed that the original guarantee system under which the earlier railways of the country were constructed, especially at the high rate of interest virtually imposed by the conditions of the time when it was adopted—a system which was abandoned in the year 1867—has turned out an uneconomical one. The additional burden imposed by the great reduction in the gold value of silver in recent years has, more-

over, to an extent quite impossible to have been foreseen, most severely accentuated the defects of the original bargain.

The actual financial position of Indian railways, as exhibited in the latest Administration Report by the Director-General, may be summed up as follows:—The total length of railways open for public traffic on the 31st March 1892, was 17,564 miles, and extensions to the extent of 1697 miles were under sanction, or in course of construction. The total capital expenditure on all railways up to the end of the year 1891 amounted to nearly 227 millions sterling.

During the calendar year 1891 the gross earnings on all railways were £24,040,279, and the total working expenses were £11,303,847, or 47·02 per cent., leaving as net earnings the sum of £12,736,432, or 5·61 per cent. on the capital outlay. Adding steamboat services and suspense accounts, the total return on the capital expenditure on all open lines of railway in the country is given as 5·76 per cent.

These figures represent the statistical results of working the railways during the year 1891. The final financial results to the State for the official year 1891-92 were only approximately known, but show an apparent net loss on all railways, taken together, of £384,450. The interest charges for the East Indian, Eastern Bengal, and part of the North-West railways, however, include annuities paid in England, which comprises a contribution amounting to about £325,000 on account of sinking funds, which will redeem the entire capital of these lines at the expiry of the period for which the annuity is to run, so that the *net loss* to the State during the year 1891 is given at the approximate figure of £60,000.

It is shown also that if interest on lines under construction were excluded from the above figures the results to the State from the working of the entire Indian railway system for the year 1891-92 would show a net gain of £190,000.

Referring to the various heads of loss, it is remarked that 'the loss on guaranteed railways is mainly attributable to the comparatively high rate at which the guaranteed interest has to be paid. Under its contracts with guaranteed railway companies the State has to pay interest at the guaranteed rates until the contracts terminate, and it is consequently unable to obtain

any advantage from the increasingly easy condition of the money market; that is to say, where the State could now raise money at a little over 3 per cent. to pay off loans raised at higher rates of interest, it has still to continue to pay interest at, or near, the high average rate of 4·8 per cent. on the capital raised by the guaranteed companies; and now, owing to the fall in exchange, the amount of rupees which have to be remitted to England to pay the sterling interest charges is equivalent to a payment of interest of over 6·4 per cent. on the total capital raised converted at par.'

The railway system of India may be divided into three main categories. First, there are lines which are the property of the State, and are managed and worked by it; secondly, there are lines which are the property of the State, but which are managed and worked by companies; and thirdly, there are lines which are both owned and worked by guaranteed companies, the Government retaining powers of purchase. Out of 17,564 miles of open railway the Government is the owner of upwards of 14,000, and has provided 153 out of the 227 millions sterling expended in their construction. The peculiar circumstances of the country have happily rendered it practically obligatory that the Government should be the ultimate holder and owner of all railway property—happily, because in a country situated as India has been, and still is, in economic and political condition, the entire possession in the hands of private companies of the main systems of railway communication, and their consequent working and management under the scarcely responsible influence of private interest, would in a manner not to be appreciated in homogeneous countries have been prejudicial to the true interests of the Indian public.

Under the practical conditions of railway working, too great importance is very often attached to the public benefits really derived from what is called a 'healthy competition.' Reasonable competition has no doubt some very desirable results; it prevents stagnation, and enforces those scientific developments which tend to reduction of working expenses and railway rates, but in practice, as a matter of notoriety, independent railway companies are soon compelled to combine in self-defence against undue loss on their part from competition, until practically a

single large monopoly is maintained, and this is liable to become a specially adverse monopoly where, as in the case of India, so large a portion of the working and management will necessarily be carried on from a distant country. Whoever holds the railways must of necessity hold a virtual monopoly, and it is distinctly better, perhaps everywhere, but certainly in India, that such a monopoly should be in the hands of the State than in those of private persons. The State, moreover, has it in its power to bestow on the public, to a far greater degree than private companies could do, the maximum advantages which the railways afford by means of the lowest tariffs.

Profits on railway working are in no way dependent on the high or low original cost of constructing the lines, but are solely dependent on the daily relation between the actual working expenses and receipts. However trite and obvious, it cannot be too often recollected that under purely commercial management it pays a little better to carry one unit for, say, eight annas, than to carry seven units for seven annas, that is to say, for the sake of one anna of additional profits a railway company is *bound* in the interest of its shareholders to exclude what may possibly be a very large proportion of public advantage. Nor has the public any reason to complain. The shareholders of a company do not make a railway for the purpose of conferring a maximum public benefit, but only for securing a maximum revenue—their object is merely to find and maintain within the limitations of the Government concession, the point of highest profits, no matter what may be the number of persons or tonnage of goods carried or excluded. If, for instance, the shareholders of a railway company were willing to accept a permanent diminution of a ¼ per cent. of their dividend, that comparatively small loss on their part might mean a possible reduction of tariffs, that would place the advantages and conveniences of railway transit within the reach of thousands who were before excluded, or, what is the same thing, would enable thousands to use the railway a largely increased number of times in the course of a given period. In India, the State, occupying a materially different position, will not necessarily be bound to sacrifice great public benefit for the sake of the last anna of profits. Its future direct revenue from railways will

form but a part of the whole receipts by which the Government of the country is carried on, and the reduction of a ¼ or even ½ per cent. on its railway income, due to a largely lowered tariff, might conceivably confer a stimulus to public activity and industry, which would set in motion a more than equivalent flow of revenue from other sources, or the public, paying only the same total, would secure an important reduction in the direct cost of railway transit.

Had, however, the true interest of the Indian public been different, the construction of the railway system of India by purely private enterprise would have been equally impossible. It is certain that neither unguaranteed British capital would have been forthcoming, nor native capital with its high ruling rate of interest, and the almost complete absence of native industrial enterprise. Again, one of the most inherent peculiarities in railway outlay is the constant and inevitable growth of capital expenditure. In a commercial point of view, once in working existence, there is no such thing possible (short of closing the railway altogether) as closing its capital account. The very condition of being of a successful railway is to increase the public demands upon it, demands which can only be met by increased outlay on new works. During the time that competition between companies owning and working a number of railways serving a given district happens to be active, the tendency to extravagantly increase capital charges is irresistible, and often disastrous, as may be witnessed in the United States of America. In India, happily, the growth of capital outlay on working lines—even under the evils of the guarantee system on its main routes—can, and has been to a large extent, kept down to a healthy and normal rate, and in this respect the country derives advantage from the largely centralised control and ownership of its railway system; an ownership, moreover, which, it should be remembered, by no means includes that direct Government agency in the working and management, which is held by many to be attended with more or less real disadvantage.

The question as to the relative advantages of State or private agency in the working and management of railways in India has been much discussed. The highly successful results of the

valuable East Indian Railway, a line which, while the property of the State, is worked by a company, compares favourably, both as regards profits and percentage of working expenses, with the best State-managed lines—and it is on many grounds probable that the employment of private agency would in every case be attended with superior economy—but the question is one to be decided not only on grounds of financial, but also on considerations of political expediency; so that it would appear that the question is rather one for particular lines or systems, than for the aggregate of railways, and that, wherever political and military interests will admit, the employment of an intermediate agency in the working and management of the Government lines may be economically resorted to.

The enormous railway property of the Indian Government is steadily and year by year growing in value, and forms one of the brightest prospects in the financial outlook of the country. This property in the now near future must assuredly place at the disposal of the Administration a perennial and increasing source of revenue, which may be of incalculable importance in relieving the burden of taxation, and in admitting the carrying out of many long-desired fiscal reforms, whilst at the same time keeping open and enlarging almost every avenue of material wealth. Another and most important aspect of the especial value of Indian railways—a value in this respect of almost inconceivable amount—is the manner in which they operate to reduce and to prevent the otherwise ruinous outlay on famine relief, in a country where, without the means of a rapid transfer, of the food supply, local scarcity, or actual famine, is just as inevitable as are the uncertainties and irregularities of climate conditions, and where the burden of directly supporting a starving population in times of local distress, has been rightly accepted as an imperial and public duty. Some idea of the cost of famine relief may be gained, when it is stated that in the eleven years 1867-1877 inclusive, no less a sum than fourteen and a half millions sterling was thus expended, and the actual cost to the public of famine relief, including remission of land revenue, in the five years, 1873 to 1878, was nearly £16,500,000.[1]

[1] *The Finances and Public Works of India*, by Sir John Strachey, G.C.S.I., and Buckley, on *The Irrigation Works of India*.

In the year 1880 the famine commissioners expressed their opinion that the trade of the country might be confidently left to provide for the supply of food in times of scarcity, basing this opinion on the rapid extension of the railway system. The thirteen years which have since elapsed have fully confirmed and justified this belief. Already in numerous cases where harvests have failed, and where unstinted public expenditure would have been unavoidable, the compensating action of railways has enormously mitigated, or altogether prevented, an inordinate rise of prices, and has thus—to say nothing of human life and suffering—saved probably many millions of pounds sterling to the taxpayers of India, and who can say how many millions more will in like manner be saved in the future? It is not too much to say, that probably in the lifetime of the present younger generation serious Indian famines will, under the equalising action of railways have become a memory of the past.

Who indeed can add up the enormous sum-total of the benefits conferred on humanity by railway communication? A celebrated English statesman has said, 'railways have rendered more services and received less gratitude than any institution in the land.' Their great wealth-creating power is very inadequately realised by the ordinary public, which adapts itself so quickly and so readily to every successfully improved appliance, and so rapidly forgets past difficulties, and the means by which they have been removed. This is perhaps more especially to be remarked in the case of steam locomotion, seeing that many persons now living could, if they reflected, correctly compare the old state of things with the new. Speaking of English railways, and of some of the ways in which they advance the wealth and welfare of a community, the author of '*Our Iron Roads*' states in far better words than any the writer of the present volume is able to frame. 'In their construction in the United Kingdom no less a sum than £831,000,000 of capital have been authorised by Parliament, and £745,000,000 have been paid up. It may be true that some of these railways "do not pay," in the sense that they do not give a reasonable dividend, or in some cases any dividend at all, to the shareholders who have provided the capital, but the poorest line that runs in the poorest district, is of value to

the trade, and to the people among whom it passes. The construction of every mile of railway, unlike money lavished in war, has at almost every stage enriched somebody, has enriched the nation and the world. Wealth employed on armies and fleets, or squandered in the destruction of life and property, or wasted in the luxuries of despotic rulers, is unproductive. Not so with railways, every pound of which honestly spent in due time yields a reward. The navvy who receives his wages for building up embankments, forming cuttings, driving tunnels, or preparing the surface of the railways; the men who are employed on the permanent way, and who keep the ballast and rails in order, the pointsmen, and the signalmen whose duty it is to watch over the running of the trains, the guards, the porters, and the stationmasters, these all expend the wages which they receive in the purchase of the necessaries, and, in not a few instances, what but a short time since would have been regarded as the luxuries of life. The producer of the goods thus distributed makes his profit on their production, and in his turn secures a share of the money which the working of the railway system causes to be circulated through the country. In like manner the coalowner, or the ironmaster, who supplies the coal and iron; the various manufacturers who build the rolling stock; each in his turn realises profits, and accumulates some fraction of the great total of national wealth. The profits thus realised become in their turn invested in reproductive works.'

The enormous economy of railway locomotion—less however in India than in Europe—if we put to its credit the diminution in the expense of traffic since it was introduced, has been strikingly illustrated by the late Sir James Allport, manager for many years of the Midland Railway, in connection with the coal traffic in England. He says, 'The reduction in the rate of the conveyance of coal to London for the last fifteen or twenty years is equivalent to the total value of the coals themselves. Twelve months ago people were paying for coals in London less than they paid for the *mere carriage* of the coals before railways came into operation'—and speaking of the general economy of railway carriage as compared with the past, he says, 'I venture to assert that the reduction in carriage by

railways, as compared with the former charges and quantities carried, has effected a saving to the country of an amount equal to more than double the entire gross receipts of all the railways of the kingdom, or more than a hundred million sterling annually.'

The indirect saving in *time*, in the conveyance both of passengers and goods, in all commercially active countries, represents also an immense direct saving of actual money in the shape of interests and discounts. It is railways alone which have rendered possible that great postal system, which oils the whole machinery of progress in every direction, and there is no exaggeration in saying that without an adequate railway system no country could ever attain that healthy activity, wealth, and well-being, which the mighty revolution effected by the locomotive engine has engendered, and which it ever, year by year, creates in wider and increasing proportion.

It is necessary, however, to remember, that great as are the developing powers of railways, the full benefits to be derived from them will not in India be realised until agricultural improvements have reached a point more nearly on a par with the increased facilities of transport. The capabilities of India in almost every branch of agriculture are enormous, but these capabilities are as yet only partially awakened. By the aid of the practical sciences which have produced so great results in Europe, the native methods of raising and preparing the main crops of the country, such as wheat and other grains, cotton, sugar, hemp, and flax, may be vastly improved, and the outturn of every acre very greatly increased. Much has been already attempted in this respect, but the difficulties to be surmounted in a country where agriculture still remains an empirical and traditional art, are exceptionally great.[1] What appears to be mainly desirable is less to revolutionise present methods, than, by careful observation to adapt and engraft on them such of the Western improvements as may be peculiarly fitted for the special conditions of soil and climate.

A second important accessory, hitherto but most imperfectly

[1] *Vide* Paper on 'Public Works in Bengal.' Vol. xvii. of *Proceedings of Institute of Civil Engineers.*

developed in proper relation to railways in India, is the creation in a systematic manner, of a network of good village roads, serviceable at all times of the year, converging on properly selected points. Without such a system of minor roads, connecting all the smaller centres of commerce with the larger and established markets nearest to the railway, the latter can confer only partial benefit to the districts through which it runs. For a long period the provision of feeder roads was unduly postponed, under the mistaken idea that the funds available would be more profitably expended on branch lines of railway to feed the main lines in the place of roads, forgetting the absolute impossibility, in such a wide area of country, of constructing within any moderate length of time a system of branch railways capable of superseding and rendering unnecessary the provision of common roads of secondary communication. The very low cost of inland carriage, principally due to the great cheapness of draft power during a considerable part of the year, tended in great measure to divert attention from the importance of good village and feeder roads in the earlier days of Indian railroads. From these and other causes the construction of such roads, serviceable throughout the year, has lamentably failed to keep pace with the wants of the railway system, and there still exists throughout the country, a large number of railway stations which are absolutely inaccessible to a loaded cart for five months in the year.

The true financial results of the large loan outlay incurred on irrigation canals in India, viewed as commercial undertakings, were for a long time the subject of some controversy, owing to the extreme difficulty of correctly assessing the total direct and indirect revenue brought about by the peculiarity of the conditions of land tenure in India, and by the virtual impossibility of apportioning the true share of the real indirect revenue between the canals and other causes—such, for instance, as the influence of improved road and railway communications. To a far greater extent than railways, all but the very smallest works of irrigation, or those constructed under some exceptionally favourable conditions, require to be in operation for a considerable period before a profitable direct return can be looked for. From this and other causes, the profit and loss in connection

with individual canals, or canal systems, throughout India varies enormously; some, such as those of Southern India, and the Jumna canals, for instance, owing to specially favourable circumstances, yielding an exceedingly high return, a few yielding a reasonable and even handsome return, and many as yet failing to pay their working expenses.[1] The net result of the whole system of canals in India, however, can be shown to be a fair and moderate return, after deducting working expenses, and the interest paid for the use of the capital borrowed for their construction. There appears, moreover, little reason to doubt that an absolutely true and complete adjustment of accounts between the land revenue and irrigation works, if such were possible, would be altogether favourable to the latter. The present direct return, probably with minor fluctuations, will undoubtedly for some time to come be an increasing quantity, whilst the influence of irrigation canals in famine protection, and in raising the general prosperity of the people within their sphere of action, is indisputable.

Their value in a country such as India must be regarded from several points of view. First, there is not only the complete immunity from famine over the large areas actually irrigated by those canals deriving their supply from permanent sources during years of drought, but at these seasons, the large surplus produce of the irrigated tracts is available to mitigate the severity of famine or scarcity over extensive areas outside them. Secondly, perennial irrigation canals, even in years of plentiful rainfall, are estimated to increase the food supply of the people in the case of rice cultivation, as much as 40 per cent. In the Madras Presidency the increase of produce due to irrigation is, according to crops, from four-fold to eight, and even ten-fold. In Northern India the rental of irrigated land is twice to three times that of unirrigated, and in Madras the proportion is much larger—up to twelve or fifteen times.

The only irrigation canals available for the prevention or extinction of famine, are those derived from the permanent rivers of the country. All other sources of supply, or of storage, ultimately dependent upon seasonable rainfall, will to a greater

[1] Vide *Irrigation Works of India.*—Buckley.

or less extent fail in times of greatest need. The number of perennial irrigation canals, therefore, as a means of direct famine prevention, is limited by the number of permanent river sources, and in many parts of India this limitation is exceedingly great. For the general purpose, however, of increasing the food supply of the people, the valuable influence of irrigation, from whatever source of water supply it may be derived, is enormous. Either the staple foods consumed by the people are raised in greatly enhanced quantities, or where such crops may not, or cannot be grown, other valuable and exchangeable products can be substituted, which without the aid of a plentiful supply of water could not possibly have been cultivated.[1] The utility of irrigation under both the above aspects is of course dependent upon a suitably connected system of communications, whether by road, navigable canal, or rail.

The outlay of borrowed money incurred on irrigation canals by the British Government in India, especially during the last thirty years, large as the absolute amount has been, is relatively small when compared with the wants of the country, so that within the limits assigned by the water supply of her rivers the future extension of irrigation works, and that even on a wider scale than anything hitherto attempted, must necessarily be very great, and the money thus expended will doubtless yield in the course of a certain time—whether the works are originally called 'reproductive' or simply 'protective'—a substantial direct return; a return, however, which admits of but small consideration as compared with the benefits and prosperity in the meantime conferred on the country, and the relief and security which such works, in due connection with railways, afford both to the natives of India, and to the public revenues.

In the examples furnished in this volume of some of the chief town water-supply schemes carried out in India, a selection has been made of a certain number of such works, which, primarily of importance and interest in themselves, at the same time serve to illustrate special and particular *types* of construction. These examples are not to be regarded as intended in any degree to

[1] Vide *The Finances and Public Works of India*, by Sir John Strachey, G.C.S.I.

indicate, even approximately, the totality of such works, the extension of which all over India, especially during the last ten or fifteen years, has been far too great to admit of any attempt to enumerate, still less to illustrate them. The particular schemes chosen will be found to include all the main varieties of town water-supply projects, and will serve as illustrations of the numerous other works of this class, of which no special mention could necessarily be made.

Although there is an immense field open for private enterprise in India, in various branches of industrial operations, it is scarcely to be anticipated that the future will bring about any notable augmentation of such enterprise, so far as concerns the employment of European capital, independently of some form of State security. But that time will remove or greatly modify some of the causes hitherto unfavourable to a fuller employment of native capital in remunerative undertakings—such as the construction of a secondary system of railways, irrigation canals, or the development of mining and manufacturing industries, either directly or in conjunction with Government agency, is exceedingly probable.

That every possible facility and encouragement should be given to native private enterprise, no one keeping in view the best interests of the country can for a moment deny, in order that India may be enabled to assume a more independent position than heretofore, with regard to the provision and expenditure of that capital on which her material progress depends. Allowing to the full the unavoidable necessities of the past, the time has now arrived when it has become only too plainly one of the first necessities of India that she should retain for her own use, not merely the indirect benefits, but also the direct profits of all capital expended. Until, however, a more active spirit of industrial enterprise has arisen among the intelligent and wealthy classes of natives, the expensive assistance of European capitalists is in some degree inevitable, and the country must in corresponding degree submit to the loss of the greater part of the direct profits accruing from her public works.

In view of the low rates of interest prevailing for some years past, and the augmenting rates of profit earned in silver by the commercial railways of the country, there would appear to be

every prospect that the issue of rupee loans for railway extension purposes, would now meet with far greater success than heretofore among native investors, and would prove a valuable stimulus to the internal and foreign trade of India.

Some relief, however, has in the meantime been afforded by that utilisation of Government credit which has allowed the borrowing of money at low rates of interest, and has permitted the construction of numerous railways, irrigation canals, and other reproductive works by direct Government agency, and has thus secured such direct profits as may accrue from these works for the service of the country; but the Government is burdened with many serious responsibilities in connection with defensive, protective, and other undertakings, from which little or no direct profit can be looked for, so that the net results in the shape of direct profits, from all Government works taken together, can hardly be otherwise than small.[1] The production of any large amount of hoarded native wealth for investment in remunerative public works would in a short time revolutionise the country, and raise it to a height of prosperity beyond present conception, nor is there any reason to doubt that such a production will in the course of time take place. Those who express surprise that the enormous hoards of potential wealth, either in specie or locked up by the natives of India in the form of jewellery, should not be more profitably utilised, forget that the very existence of these hoards is but the expression of that innate feeling of the insecurity of all possessions not susceptible of removal, which is the legacy left by the ancient forms of government. This feeling, engrained in the native character, the past experience of the race has tended to harden into a fixed and hereditary instinct. Already under years of settled government, less intense than formerly, this innate distrust must in the course of time grow more and more feeble, in proportion as, under a wise and judicious administration, the country is maintained in a condition of internal contentment and external security. Probably also it will gradually be more clearly perceived by the wealthy and cul-

[1] Vide *The Finances and Public Works of India* 1869-1881, by Sir John Strachey, G.C.S.I.

tivated classes of India that returns from capital employed in industrial operations, and in developing the resources of their own land, by means of public works permanently affixed to the soil, must, as their own power and share in shaping the destinies of the country, under the conditions of a growing civilisation, increases, tend to become more and more independent of minor contingencies. Under the stimulation of the growth of confidence, and of material progress, the effective desire of accumulation must steadily augment, and the high normal rate of interest will necessarily fall. It is probable therefore that a greater employment of native capital in remunerative public works is to be looked for in the near future, and that some notable proportion of that enormous amount of gold at present absorbed by the country, and devoted to the idle and unprofitable shape of concealed treasure and of ornament, will gradually be released and rendered available for both private and public benefit.

At the beginning of the year 1889 it was estimated that 'there was lying in India a stock of gold bullion wholly useless for commercial purposes, and increasing at the rate of nearly three millions annually, of the value of not less than £270,000,000 at the market, being probably two-and-a-half times as great as all the gold money in circulation in the United Kingdom.' One-half of this gold released, and put into a material form, represents the present equivalent of 14,000 miles of railway communication, yielding a probable direct return of nearly seven million pounds per annum. In the early part of the year 1892 the *Calcutta Englishman* stated that 'India still shows an unabated appetite for gold, which it continues to absorb in a wonderful way. During the last eight months the yellow metal, to the value of 356 lakhs—or £3,560,000—has been imported, and deducting the re-export of 70 lakhs, there remains 286 lakhs, or £2,860,000, which will probably go bodily as a permanent addition, mainly in the shape of jewellery, to the hoards of the country. The imports of silver amounted to 536 lakhs, and the exports to 116 lakhs, leaving a residuum of 420 lakhs.'

As yet there are but few signs that this passion for hoarding the precious metals is on the wane. It is noticeable, that the

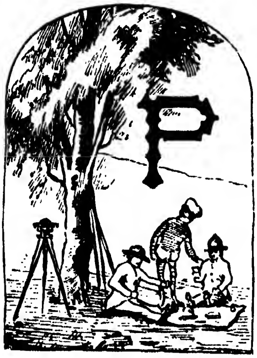
more educated and anglicised portion of the natives of the country are less under its influence than others; something in this direction therefore has already resulted from the spread of education. Much can also be hoped from the raising of the general status and intelligence of the better classes of women. The movement in the direction of decreasing marriage expenses will also operate favourably, as well as the more extended facilities for the profitable investment of small sums of money by the Post Office and other savings banks, but the only real and important influence which will widely open the door of this treasury of hoarded wealth is the lowering of the rate of interest, in response to the growth of that settled confidence in the security of invested funds, intrusted beyond the immediate control of the owner, which lies at the root of all enterprise in any country, and the low degree of which in India is the still lingering and unhappy consequence of centuries of early oppression and spoliation. The action of this influence, operating as it has to do in the face of the inherent unenterprising spirit of an essentially agricultural country, and of climatic conditions unfavourable to the expansion of the highest energies of man, must, on the whole—although not of necessity locally—be very slow and gradual.

The Parsee community of the Bombay Presidency supplies an example of what may be done by an Eastern race in which the commercial and enterprising spirit has been freely developed under secure and liberal government. In the advanced Province of Bengal indications of a growing spirit of public enterprise have for many years been apparent, and every judicious and successful example of the remunerative employment of native capital, in works of public utility, whether in the form of railway construction, irrigation canals, mining industries, or in any other of the innumerable fields of industrial energy, will be a benefit not only to the enterprising projectors themselves, but also of incalculable service to the welfare and progress of India.

GREAT INDIAN TRIGONOMETRICAL SURVEY

CHAPTER I

Meaning of the term 'Trigonometrical Survey'—Elementary example—Description of a small survey—Base line and signal stations—Base of verification—Plotting the triangles—Internal details—Network of triangles—'Gridiron' system—Well-conditioned triangles—Measurement of base lines—Method of enlarging a base—Description of Gridiron system—Recapitulation of methods of trigonometrical surveying.



POSSIBLY a few of the readers of this volume may have but a very faint idea of what is meant by a Trigonometrical Survey, others may have a general notion that it means some method of measuring the ground for the purpose of map-making; but as to how, and in what particular manner, a correct map of a country is made, they are more or less ignorant. All people, however, perfectly understand that to be of any practical use a geographical map must be an accurate representation, on a small scale, of the exact shape of a country, and of its various divisions, and that all places marked on it must measure—by the scale attached to the map—the real and actual distances from any one point to every other, that is to say, every town, village, river, mountain, or boundary, must be placed in its true relative position the one to the other.

No one has any difficulty in seeing that distances can easily enough be measured on the ground—along a given line for instance, supposing there are no obstacles in the way—or similarly along any number of lines, but further than this most people, unless previously conversant with the methods of surveying, fail to perceive how all these measurements are to be *combined* and tied together on paper so as to form a correct

whole answering to the real form of the country, and within the most minute limits of error, exact in all its linear dimensions, measured in every possible direction.

Now, as it is our purpose to give an outline sketch of the operations of the 'Great Indian Trigonometrical Survey,' a few words of general explanation to the entirely uninitiated reader, which will enable him to understand in a general way what is meant by a Trigonometrical Survey, will, as a preliminary, be desirable.

First of all, then, the word 'Trigonometry' means *measurement of triangles*—from the Greek words τρίγωνον, a triangle, and μέτρια, measurement (from μέτρον, a measure) so that a trigonometrical survey means a survey made by means of the measurement of triangles. In what way the '*measurement of triangles*' enables us to carry out a geographical survey will now be explained as simply as possible.

Let it be assumed that a reasonably correct plan or map of a small island is required, and that a survey party—which we are privileged to accompany—has been formed to execute the necessary field-work. Further, to eliminate all disturbing conditions, let it be assumed that the island has a generally plain surface, entirely free from forest growth, and from all objects offering impediments to a clear view in every direction. The survey party will be equipped with a few steel measuring chains, a good supply of poles and flags, and one or two highly refined and accurate instruments for measuring angles, called *theodolites*.

If the island is completely new and unknown ground to the party they will first of all explore it carefully, making what is called an 'ocular' survey—so as to gain a general idea of its main features, and of the position of its prominent points. Its approximate size will also be estimated by the length of time required to traverse it in one or two directions at a roughly known rate of travel. The next operation will be to select—probably somewhere along the flat, sandy shore—a fairly level and unencumbered surface, on which a long straight line can be measured. This line, which will form the initial base of the whole survey is called the '*base-line*.'

A suitable position for this important line having been found,

a number of flag-posts, or signal 'stations,' will be planted probably on, or near, the coast line, each placed on ground as elevated as possible, in order that it may be visible from at least two other stations. The position of these signal-stations will be selected with great care, and they will be arranged so that a series of lines running from one to the other will parcel off the whole island into several large triangular spaces, and the line which has been selected as a 'base' line will form a side of one of these triangular spaces. The position of the various signal-stations, which are to form the meeting-points of the lines enclosing the triangles, having been fixed, the party will proceed to measure the exact length of the 'base-line.'

Now the length of a 'base-line' requires to be measured with the most extreme attainable accuracy, because, if this line is wrongly measured, all the rest of the work based on it must be wrong with it; consequently a great deal of trouble is taken to ensure the accuracy of this measurement. Either the ground is levelled very carefully, or it is so arranged that the steel chain with which the measurement is about to be made, shall, when stretched very tight from point to point, be a true, straight, and level line. First of all the length of the measuring chain is checked with a 'standard' chain brought by the party to see if it exactly corresponds, and, if not, it is adjusted. The surveyors then proceed to measure carefully the length between the two flag-posts which have been planted to mark the extremities of the base-line. They are not satisfied with measuring this once, but they measure it several times over—first one way and then the other, repeatedly checking the length of the measuring chain with the 'standard' to see if it has stretched or altered at all under use. When they have obtained, a good many measurements taken backwards and forwards along the base line, it is found that, although very near each other, no two of the measurements agree quite exactly. The divergence, however, unless great, is of no consequence. All that it is necessary to do is to add all the various lengths together and then divide the sum by the number of times the measurement has been made, and thus a *mean* length is obtained, which will be sufficiently near to the true length to answer the purpose in view. To enable our readers to follow the progress

of the work, we here insert a rough sketch (Fig. 1) of what in the first instance is guessed to be the general shape of the island, and on this sketch we have marked the probable position of the flag-posts which have been planted near the coast. We have also inserted letters which indicate the angles of the various triangles that the surveyors propose to measure, and we have numbered the triangles themselves from 1 to 5. Having completed the measurement of the base-line, marked in the fig. *a-b*, a 'theodolite' or instrument for measuring angles

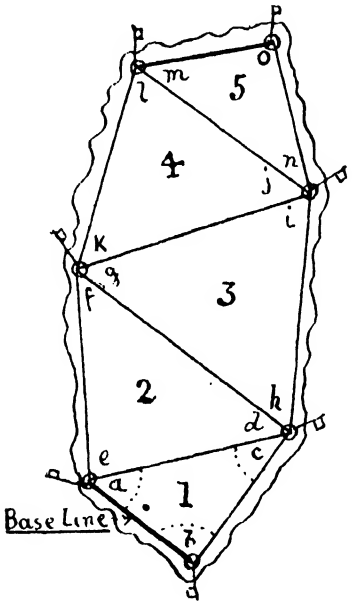


FIG.

is set up at the point *a*, and the surveyor carefully measures the angle at *a*, sighting alternately the-flag posts at *b* and *c*. Having recorded this angle, the surveyor removes the instrument to the *b* end of the base-line, and in a similar way measures the angle *b*, sighting alternately the flag-posts *a* and *c*.

Of triangle No. 1, the length of one side, viz., the 'base-line,' which has been directly measured, is known, and the size of each of the angles *a* and *b*. Having this information, by a simple *calculation* the size of the distant angle at *c* can be discovered without actually measuring it with the theodolite, as also can

be the lengths of the two sides *a c* and *b c*. These lengths, obtained by calculation, will, if the length of the base-line and the angles which have been measured are correct, be far more accurate than if they had been measured directly on the ground with the measuring chain. Knowing in this manner the length of the side *a c* (which is also a side of No. 2 triangle) it can be treated as a new base-line, and after the angles at *e* and *d* have been measured, another calculation will give the size of the angle at *f*, and also the lengths of the sides *e f* and *d f*. The surveyor can now treat *d f* as another new base-line, and by its means, and by measuring the angles at *h* and *g* he can measure the third triangle. From the side *g i* of this triangle, the length of which is obtained as before by calculation, he can measure the fourth triangle, then, proceeding in exactly the same way, he is able to measure the fifth and last triangle.

Now, in order to see if the work hitherto done is quite correct, one side of the last triangle, say *m o*, is very carefully measured with the steel chain, in precisely the same manner as the original base-line was measured. If it is found that the length *m o* as given by calculation, and as found by direct measurement, agrees exactly or very very closely, the trigonometrical work is done, but if by calculation it works out altogether different from the measured length, then it is known that there is a great mistake in the work somewhere, and it will be necessary to do it all over again, until the mistake is discovered and corrected, and until the two measurements at last practically agree.

It will now be clear that, having the angles and the exact lengths of the sides of each of the five triangles, the surveyor can—to any scale he likes to select—draw, or what is called 'plot' these triangles on a sheet of paper, and it will be certain that their sides and the points where the flag-posts are erected will have their relative dimensions, and lie in their true relative positions, the one to the other. If care is now taken to mark in a permanent manner on the ground, the points occupied by the flag-posts, it will be possible at any subsequent time to complete the survey of the details of the island. The *triangles*, which have been correctly laid down on paper, will serve as a skeleton or framework for everything else required. For example,

it is desired to draw on paper the exact outline of the coast. All that it is necessary to do is to measure a sufficient number of what are called 'offsets' from the sides of the triangles nearest to the shore, thus supposing *e f* in Fig. 2 represents the precise length, to scale, of the side *e f* of No. 2 triangle, stations, situated opposite the chief points of irregularity in the shore-line are measured off on the ground along this line from the point *e*. From each one of these stations, and at right angles to the line *e f*, an 'offset' is measured to the shore. These measurements having been entered in a book, it is evident that the 'offsets' can be drawn or '*plotted*' on the plan of triangulation, and by drawing a line through the outer ends of the 'offsets,' the exact outline of the coast between the points *e* and *f* will be produced. When it is desired to fill in and add to the plan the inland features of the island, the surveyor can, either by means of smaller triangles laid down inside the main ones, or by running any desired number of measured lines tied to the sides of these triangles, obtain lines, 'offsets' from which will give all the interior features with any degree of detail desired, or suitable to the scale on which it is proposed to draw the map. The important matter to notice is that every point of the detailed filling up will be in its correct place, because all will be tied and held together in exact relative position, on and about the main lines of triangulation, which constitute, in fact, the skeleton on which the whole body of the map is moulded. 13255

FIG. 2.

The above serves merely as an illustration of a simple framework, consisting of a single series of triangles grounded on and verified by two measured bases. The island that has been dealt with is in reality so small that a perfectly correct map of it could very likely have been obtained by a few simple direct measurements, without the necessity of any angular measurements at all.

When it is necessary, however, to provide a suitable skeleton or framework for the detailed survey of a very large continent,

island, or other surface, there are two methods usually employed, one is to spread in every direction by means of a *network* of triangles a series of fixed points, from and within which the topographical or detail surveyor can securely work; the other, which for the most part has been employed in India, is to lay down a series of chains of triangles following, say, north and south lines, connected together by cross series of east and west chains, forming thus a sort of *gridiron* of chains of triangulation. The interior area of the triangles themselves, and also the areas of the interior spaces between the chains forming the gridiron, can then be readily surveyed in detail; the areas to be filled in being brought down to manageable dimensions.

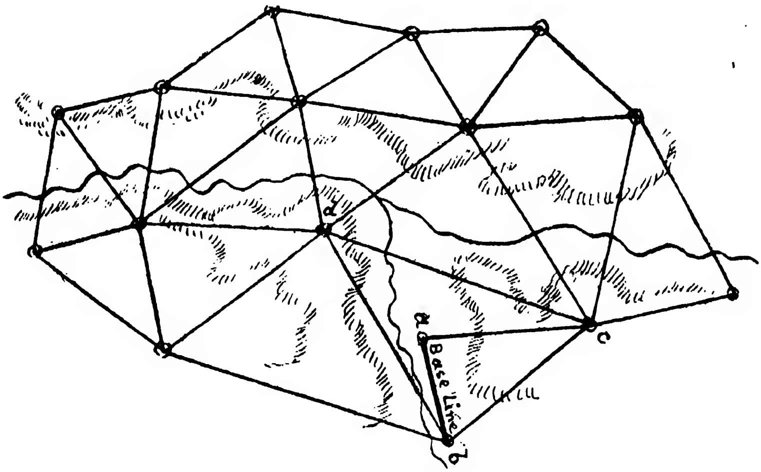


FIG. 3.—NETWORK SYSTEM.

In such a triangulation or rather 'trigonometrical survey,' the sides forming each of the main triangles may be as much as fifteen to thirty miles in length, so that the mere ranging and sighting of the distant points or stations will require not only the most perfect optical instruments but will often, from physical causes, present problems of extreme difficulty in practical solution. The measurement of the various base-lines of origination and verification—each probably many miles in length—will also involve the most extreme nicety of measurement.

In order to make quite clear the meaning of a *network* and of a *gridiron* system of trigonometrical survey, Fig. 3 is a repre-

sentation of a network system, and Fig. 4 of a gridiron system. In each, the little circles represent stations or observing points from which angles are measured, which, wherever possible, are fixed on the highest elevations.

Looking at Fig. 3 it will be seen that the triangles forming the network are all what is called 'well-conditioned,' that is to say, they have no very sharp or very wide angles. It is, in fact, a general rule in all trigonometrical triangulations that no angle shall be sharper than 30 degrees, or wider than a right angle or 90 degrees. The measured base-line *a b* will be found

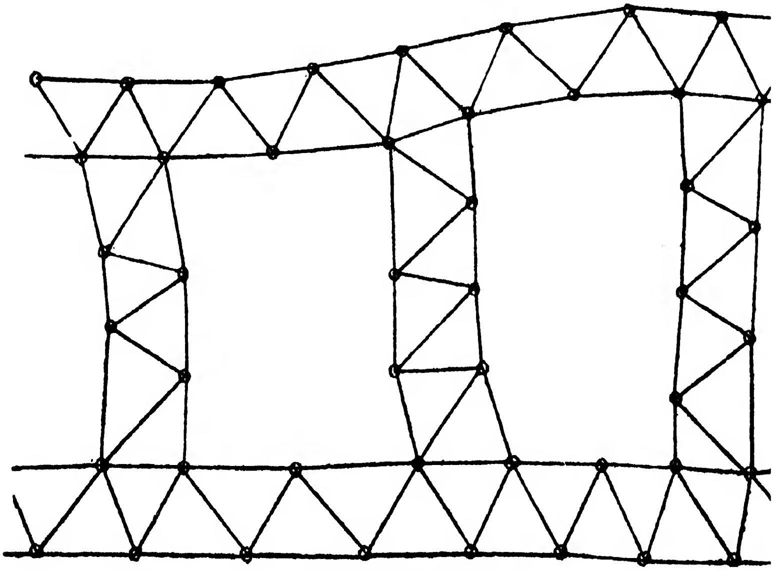


FIG. 4.—GRIDIRON SYSTEM.

marked on the lower right-hand corner of the sketch. As before explained, all trigonometrical operations in the first instance, start from some actually measured base-line, and it has been noted that the correct measurement of this base-line is a matter of the first importance, because from it the length of the sides of a whole series of triangles has to be computed, which computation will be all wrong if the base-line has not been correctly measured.

Although apparently a very easy matter, the exact measurement of a long base-line is in reality an exceedingly difficult

operation, and every expedient that ingenuity can devise has to be employed in order to obtain the necessary accuracy. It is desirable that the length of a base-line for a primary trigonometrical survey should be as great as possible, but circumstances seldom permit it to exceed more than seven or eight miles in length, because, in the first place, a fairly level and unencumbered surface has to be selected, so that each end of the base may be visible from the other end; and secondly, it is necessary that conveniently situated signal stations, suitable for laying out 'well-conditioned' triangles with the base-line, should also be clearly visible from both ends, and these conditions are only rarely to be found. Where only a short base is obtainable, there are, however, convenient ways of deriving from it, by means of a triangulation, much longer lines, say ten or twenty miles in length, from which a continuation of the triangulation can proceed. One such expedient is shown on sketch-plan, Fig. 3, of a network system. From the short base-line marked *a—b* a triangle, *a*, *b*, *c*, is laid out, having its apex at the station *c*, and with an angle at this point not less than 30 degrees. Having calculated the length of the side *b c* of this triangle, another one, much larger, can be laid out from it as a base, having its apex at the station *d*. The length of the side *c-d* can now be calculated, and in this line we have one considerably longer than the original base-line.

Some of the expedients employed in the measurement of base-lines will be described further on. For the present, turning to Fig. 4, we have a representation of a simple *gridiron* system of chains of triangles, such as has been adopted on the Indian Trigonometrical Survey. The country to be surveyed is traversed by a series of such chains of triangles, crossed by other chains, leaving relatively large spaces between them. This method of trigonometrical surveying is considered superior to the network system, because it is simple, contains fewer triangles, and these capable of more regular and systematic deduction, the one after the other, than is the case with a network. In practice, however, on a very large surface of country, the two systems are in reality combined, the main framework of the survey being the gridiron, whilst between the chains forming the gridiron, a secondary network of triangles, of gene-

rally smaller size than those which compose the chains, is filled in, this network being of course dependent on, and connected to, the sides of the primary triangles forming the chain. In course of time, under the operation of a detailed survey, the secondary network may be still further broken up into smaller and smaller triangles, or traversed with cross lines in every direction, each line being tied and bound into its proper relative position, as also will of necessity be the position of every geographical feature of the country, which is measured from, and fixed by means of offsets or other means, from one or other of these intermediate lines.

To recapitulate, it will now be clearly understood that trigonometrical surveying consists—First, in the selection of suitable sites for, and the accurate measurement of, base-lines for the origination and verification of either a complete network of triangles, or of long chains of triangles, across a given belt of country. Secondly, the selection of suitable intermediate points, such as prominent hill-tops, or specially selected or constructed lofty towers, for the meeting points of the lines, forming in each case 'well-conditioned' triangles. Thirdly, the fixing of the exact position of these intermediate points, by means of measured angles and calculated sides of triangles, starting from the measured base, and carried successively through the intermediate points, so as to form either a network or a chain of triangles. The accuracy of the intermediate computations is then verified by means of a measured base at the other extremity of the network or chain.

The trigonometrical survey of the entire country is completed either by covering the whole area to be surveyed with a network of triangles, or by carrying a sufficient number of ranges of triangles, longitudinally and laterally across the country, so as to form a sort of gridiron. The work is also further checked by means of astronomical observations for obtaining the exact latitude and longitude of numerous selected spots over the whole area. The principal triangulation is then handed over to detail surveyors, and all the interior spaces are filled up with a secondary triangulation, which may be again broken up into tertiary triangles, within which the detailed features of the country can be closely measured, and their positions accurately fixed, by means of 'offsets,' or in other various ways.

CHAPTER II

Early Geography of India—Major James Rennell's surveys in Bengal—Route maps—General atlas of India—Advantages of trigonometrical triangulation—William Lambton, father of Indian surveys—Proposes measurement of arc of meridian, and trigonometrical survey of southern portion of India—Objects in view—Proposals submitted to Madras Government—Lambton appointed to conduct operations—Instruments employed—Commencement of operations, 1802—Madras Observatory—Measurement of the first base-line—Correction for temperature—Triangulation carried to opposite coast—Inaccuracy of former route surveys—Origin of 'Great Arc Series'—Base at Bangalore—Injury to great 36-inch theodolite—Early opposition to survey operations—Demonstration of their utility—Recognition of Colonel Lambton's services—Great arc series carried to Beder—Captain Everest appointed chief assistant—Colonel Lambton extends arc series to Takal Khera—His illness and death—Summary of his great labours—Everest appointed his successor.

Less than 150 years ago the geography of the interior of India was very little known. At that time the only knowledge of the country was derived from the descriptions of the routes of occasional travellers into the interior, and from the rough charts of the coast lines made from time to time by English and foreign marine surveyors. About the year 1755 an English edition of a French map of India, compiled from such sources, was published. Shortly after this time, and up to the year 1782, Major James Rennell, an East India Company's officer, who was appointed Surveyor-General of Bengal, did much geographical work in that province. Major Rennell surveyed, by means of chain measurements, a tract 900 miles long by an average of 300 miles broad, taking observations for latitude and longitude at various points, and his map of the districts of Bengal and Bahar was published in 1781. From this time various route-maps of different parts of the country were from time to time obtained by special surveyors appointed to accompany armies in the field.

In Madras, the latitude and longitude of numerous points were astronomically fixed, the coast line was laid down for a distance of 700 miles, and upwards of 2000 miles of route measurements were made in the Carnatic during the war with Hyder Ali. From the material thus accumulated, a general atlas of India was nearly completed in 1787, but owing to the fragmentary nature of the surveys, and the numerous errors contained in them, little practically useful results were obtained. Further materials, however, slowly accumulated from numerous route surveys, and carefully computed astronomical observations, until the year 1798, when the results were sent to England for the purpose of framing a great map of India which, however, was never published, and much of the interesting and valuable data collected is said to have been lost in the destruction of old records which took place at the time of the abolition of the East India Company. These various route surveys, greatly inaccurate as they necessarily were, were at the time when the interior of India was almost unknown of great service for the use of armies on the march, but as the country was gradually brought under British administration, the want of good and accurate maps of the districts became more and more keenly felt. At the beginning of the present century the method of surveying a country by means of measured routes, and positions astronomically fixed, was more and more seen to be liable to serious errors, and it slowly began to be recognised that a trigonometrical triangulation was the only really secure basis for accurate map-making, although many experienced men brought up under the old system still believed in, and clung to, the earlier practice. Great improvements and refinements were introduced into the manufacture and accuracy of mathematical and optical instruments for astronomical and surveying purposes, and the results so far obtained in the progress of the trigonometrical survey of Great Britain, which was commenced in 1784, showed the many advantages of the trigonometrical system.

The magnificent undertaking known by the name of the 'Great Indian Trigonometrical Survey,' consisting of chains of triangles, which extend from Cape Comorin to the borders of Tibet, and from Afghanistan to Burma, was commenced about

the year 1800 by a man possessed of that indomitable ardour and perseverance of which heroes are made, a man whose name will always stand in the forefront of the great achievement he initiated, and whose death on the field of his labour, at the age of seventy, after twenty-three years of battling almost single-handed with the most formidable obstacles, in the midst of a terribly baneful climate, must always render his career memorable in the list of willing martyrs to science and to duty. William Lambton, who was an entirely self-taught man, was born in the year 1753. Very little is known of his early life except that he obtained a commission in the 33rd Regiment, and owing to his having acquired a knowledge of surveying, he was for some years employed as a land surveyor in America, where he devoted himself ardently to the study of the higher mathematics. In 1797, being then forty-four years of age, he rejoined his regiment, at that time in Calcutta, and shortly afterwards saw service in the war with Tippoo in Mysore. After the successful termination of that war, Captain Lambton brought forward a proposal for the measurement of a long arc of the meridian, that is, a long north and south line, and for a trigonometrical survey of the southern portion of India. Its object, to quote his own words, was 'to determine the exact positions of all the great objects that appeared best calculated to become permanent geographical marks, to be hereafter guides for facilitating a general survey of the peninsula.'

Lambton proposed laying out a network of triangulation from Madras across to the opposite coast, for the purpose of fixing the breadth of the peninsula on that parallel, at the same time making observations for obtaining the exact latitude and longitude of numerous important places. The accurate measurement of a long arc of the meridian, such as could be obtained in India, was a matter of the highest importance from a scientific point of view. By its means the true curvature of the earth could be obtained, and the astronomical tables used in navigation (which are affected by the shape of the globe) would be perfected, whilst the triangulation necessary for the measurement of the arc would serve as the principal axis of a system of triangulation to be extended over all India, on which a correct geographical map of the country could be built.

Captain (afterwards Colonel) Lambton's proposals were submitted to the Madras Government, and were warmly supported by the Marquis of Wellesley. The Governor of Madras was also favourably impressed by the advantages likely to accrue from the undertaking, and sanction to it was shortly afterwards accorded by the Government. Colonel Lambton, as a matter of course, was appointed to conduct the operations. Lieut. Warren of the 33rd Regiment, and Lieut. Kater, were appointed assistants. The chief instruments employed by Lambton were a 36-inch theodolite (a highly refined instrument for measuring angles with extreme accuracy), an 18-inch repeating Theodolite, both by Carey, and several smaller ones; an astronomical instrument called a 'zenith sector,' by Ramsden; two measuring chains of blistered steel, and a standard brass scale. The large theodolite was unluckily captured by the French on its way out from England, but it was afterwards chivalrously returned by the French Governor of Mauritius, with a complimentary letter to the Governor of Madras. The steel chains were 100 feet long, consisting of 40 links of 2½ feet each, of excellent manufacture, in fact, the whole of the instruments were the most perfect that were at that time obtainable in England.

Operations commenced on the 10th April 1802, by the measurement of a base-line, something over 7½ miles long, near St. Thomas Mount, Madras. The Madras observatory, then for some time in existence, thus became the starting-point of the Trigonometrical Survey of India. By means of a long and regular series of astronomical observations, the longitude of that observatory was more accurately known than any other point in the peninsula, and this longitude served—as it still does—as the local meridian, in place of the meridian at Greenwich, to which all the observations for longitude in the Indian surveys are ultimately referred.

In measuring his first base-line at Madras, Colonel Lambton used a chain similar to that employed by the English Ordnance Surveyors. The chain was supported in five wooden boxes, each 20 feet long, which were carried on tripods, fitted with elevating screws, the whole being adjusted to exact line by means of a telescope. At one end the chain was secured to a 'draw-post,' with provision for adjustment by means of a fine

screw-movement. Near the handle was a brass scale, with minute divisions, fixed on the head of a separate post. This scale, by means of an adjusting screw, could be moved backwards or forwards until it exactly coincided, under a magnifying glass, with a dot or mark on the chain, from which its measuring length commenced. At the other end of the chain was a similar arrangement, but the handle here instead of being fixed to a 'draw-post' had a rope passing over a pulley, to which rope a 28-lbs. weight was attached, to keep the chain tightly stretched. Thus the two ends of the measuring length of the chain could be accurately brought into position. This done, it was moved forwards, and a new length measured, and so on, until the base was finished. The temperature of the chain was determined by means of thermometers placed inside the boxes, and the rate of expansion having been fixed by previous experiments, the necessary corrections could be made. This correction in all amounted to ·00725 inch for every degree of Fahrenheit. All measurements made with the steel chain were reduced to that of a standard chain, whose length had been fixed at a temperature of 50 degrees. The measurement of the Madras base occupied forty-two days, when observation was taken to determine the angle formed by the base with a meridional, or true north and south line.

It may be mentioned here, that although the above method of measuring a base-line was employed in several cases in the earlier stages of the survey, it was subsequently superseded by a greatly improved system, to be explained further on, and all the important base-lines measured with the steel chain, were afterwards re-measured with the improved apparatus.

After some time spent in experimental trials in the neighbourhood of Madras, Lambton and his staff carried a series of triangles inland from the Madras base, in a westerly direction, to a point situated near Bangalore (see Map of the Triangulation). Here in May 1804 a base of verification was measured. The distance was 160 miles, and the measured and calculated length of the new base was found to differ by 3¾ inches only. From the Bangalore base-line triangles were then laid out across the remaining width of the Peninsula, to the west coast near Mangalore. The complete distance across from Madras

to the Malabar coast was found to be 360 miles, or 40 miles less than had hitherto been given by the best maps. The inaccurate results obtained by the earlier methods of survey was thus demonstrated.

The base-line measured on the Mysore plateau at Bangalore, was adopted as the origin of the long meridional series of triangles which was ultimately (not, however, before the year 1837) carried up from Cape Comorin to the foot of the Himalayan mountains. This immense range of triangles, 1540 miles in length, is named the 'Great Arc Series.' At the time it was completed it was—and it is believed that it still is—the longest arc measured on the earth's surface. Starting from the Bangalore base, the 'great arc' triangulation was first gradually carried down to a point near Cape Comorin, where a base of verification was measured, then in the year 1811 Colonel Lambton commenced its northward extension from Bangalore.

During these early years of the survey the operations were constantly interrupted by the disturbed political condition of the country, which was not completely pacified until the year 1818, as well as by the jealousy and apprehensions excited in the minds of the people at the sight of the mysterious proceedings of the surveyors, with their strange and uncanny looking instruments perched successively on almost every hill-top, and their long array of flag-posts and signals which seemed to pervade the country. Whatever may have been the exact nature of the opinions or fears thus aroused, it is evident that much patience, firmness, and tact, were requisite on the part of the officers of the survey in order to avert danger, allay suspicion, and conciliate goodwill. Additional obstacles to progress were also imposed by the untrained condition and inexperience of the subordinate staff, and by the constant sickness of the field-parties exposed to a highly malarious climate. The stay of the two officers appointed as assistants, was too of but short duration. The services of Lieut. Warren were before long required elsewhere, and Lieut. Kater's failing health soon obliged him to quit the service. Thus the chief of the survey was often compelled to work nearly single-handed, and he had to turn his time and attention to many harassing details. It

is recorded that on one occasion when the great 36-inch theodolite—the mainstay of the operations—was being hoisted to the top of a lofty pagoda tower, the tackle broke, and the instrument was seriously injured; the main limb having been completely bent out of shape. Such an accident, occurring at a time when no experienced artificers accustomed to the repair of such delicate instruments were to be found in India, was a severe blow. Colonel Lambton, however, was not disheartened. He carried the broken theodolite to Bangalore, and by his personal labour, assisted by some workmen from the Artillery establishment, after six weeks' delay he succeeded in completely repairing the injuries, and the instrument was made as good as ever, continuing in use up to the year 1830.

The work on the southern portion of the 'great arc series' is far from representing the full extent of Colonel Lambton's labours at this period. By the year 1815 he had covered the greater part of the country between Madras, Bangalore, and the Godavery river with a network of triangulation, fixing the position of all the more important points extended over this area, and carrying out simultaneously an immense number of astronomical observations. He was, moreover, harassed by frequent opposition from the highest quarters, calling in question the fundamental utility of his operations, it being still maintained that the old system, based on route surveys, and astronomically fixed positions was equally accurate, and more economical. He was also kept ill-supplied with money by the financial authorities at Madras. It was only after long and tedious argument and correspondence that he at last successfully refuted his opponents, patiently demonstrating the many serious errors in the position of numerous places, as fixed astronomically on the old maps. Not only was the breadth of the Peninsula on the Madras line forty miles wrong, as previously stated, but the position of Arcot was shown to be ten miles out of place, and Hyderabad no less than eleven minutes in latitude, and thirteen minutes in longitude. It was not until the year 1818 that he at last succeeded in completely vindicating the utility, and demonstrating the extreme importance of the labours on which he was engaged, and this only after their value had been fully recognised and appreciated

by numerous scientific bodies in Europe. In 1817 he was made corresponding member of the French Institute, and in the following year was elected a Fellow of the Royal Society.

In the meantime the 'great arc series' of triangulation (all work on which was conducted with special care and accuracy) had been pushed northwards to Beder, in latitude 18° north, where a new base line was measured. Colonel Lambton, now at the age of 65, had greatly broken down in health and physical energy, and Captain Everest, afterwards his able successor, was appointed as chief assistant. Owing to the disturbed condition of the provinces of Central India at that time the 'great arc' work was temporally suspended, and Everest was employed in completing the network of triangulation to the southward, where in 1820 he was disabled by fever, and had to proceed to the Cape of Good Hope for the recovery of his health. Colonel Lambton, much broken in health as he also was, then proceeded with the 'Great Arc Series,' extending it up to Takal Khera in latitude 21° 6′. More and more prostrate by disease and infirmities of age whilst vainly attempting to measure a base-line at Takal Khera, he exposed himself so unduly to the severe tasks imposed upon him by the sickness and prostration of nearly all his party that he completely broke down. Soon afterwards setting out from Hyderabad to Nagpore—still in prosecution of his work—he died on the road at Hingunghat, now a large cotton centre in the Central Provinces, on the 20th January 1823. A modest tomb, consisting of a pillar surrounded by a walled enclosure, was afterwards erected over his remains by the Resident at Nagpore, on the bare ridge not far from the spot where the water-works reservoir now stands.

Thus died in harness, at the age of 70 years, the worn-out 'Father of the Indian Survey'—like many of his humble followers, a faithful martyr of devotion to the public service. His last great work comprised a triangulation aggregating 165,342 square miles of the Peninsula of India, at a total cost of £83,537, or an average and moderate outlay of about 10s. per square mile. About the year 1820 Colonel Lambton in a report on the survey operations writes, 'In the twenty years devoted to this work I have scarcely experienced a heavy hour,

such is the case when the human mind is absorbed in pursuits that call its powers into action. A man so engaged, his time passes on insensibly, and if his efforts are successful his reward is great, and a retrospect of his labours will afford him endless gratification. If such should be my lot I shall close my career with heartfelt satisfaction, and look back with increasing delight on the years I have passed in India;' and again in his last report he says, 'It would indeed be gratifying to me if I could but entertain a distant hope that a work which I began should at some future day be extended over British India. I sincerely hope that after I relinquish the work somebody will be found possessing zeal, constitution, and attainments, wherewith to prosecute it.'

This hope was amply realised in the person of Captain, afterwards Colonel, Everest, who was shortly afterwards appointed his successor.

CHAPTER III

Continuation of Great Arc Series to Sironj—Ill-health of Superintendent—Absence for five years—Calcutta Longitudinal Series—Useful work of Everest in England—Colonel Colby's compensation bars—Description of apparatus—Return of Colonel Everest to India, 1830—Measurement of Base of verification at Calcutta—Northward extension of Great Arc Series—Erection of permanent towers—Site for northern base of Arc Series—Connection of base with Sironj—Re-measurements and revisions—Results—Observatories—Completion of Great Arc Series—Bombay Longitudinal Series—Retirement of Colonel Everest—His substitution of a Gridiron for Network System—North and South ranges of chains one degree apart—Modification—Calcutta Meridional Series—North-Eastern or Himalayan Series—Deadly tracts of the Terai—Loss of life and health—Base of verification at Sonakoda—Himalayan Peaks—Mount Everest—East Coast Series—Difficulties—South Kankan Series—North-Western Quadrilateral—Prolongation of Calcutta Longitudinal Series to Karachi.

Captain Everest whilst on sick leave at the Cape of Good Hope, had opportunities of studying the Abbé de la Caille's arc measurement, and he contributed a valuable paper on the subject to the Astronomical Society. On his return to India he was engaged at the time of Colonel Lambton's death, in laying out a series of primary triangles, intended to extend from the Beder base-line to Bombay. In consequence of the death of his chief, he succeeded to the office of Superintendent of the Survey, having been for five years chief assistant. Captain Everest at once transferred his attention to the continuation of the 'great arc series.' After many difficulties consequent on defective staff, sickness, and the nature of the country, he carried on the triangulation from Takal Khera to latitude 24° North, where, in the year 1824, a base-line was measured with the old chain at Sironj (situated about seventy miles south of Bhopal), near which place a lengthy series of astronomical observations was also undertaken.

The health of the new superintendent, however, again broke

down, and he was obliged to go to England in 1825 to recruit, remaining absent from India for about five years. He still, however, retained his appointment, there being no person then competent to succeed him in so important a post. It was not, however, necessary that field work should be suspended, there being by this time many able and experienced assistants on the survey establishment. A party was therefore organised to carry on during Captain Everest's absence, and in accordance with his written instructions, a long chain of triangles, to extend from the Sironj base-line to Calcutta, a distance of nearly 700 miles, over a wild and unhealthy tract of hilly country, the survey embracing an area of over 33,000 square miles. This chain of east and west triangulation was named the 'Calcutta longitudinal series,' and it was carried on in the face of severe obstacles and difficulties, at an average rate of about 112 miles per year, so that when Captain Everest returned to India in 1830, the greater part of the distance had been covered. It was not, however, until the year 1832 that the series was finally closed on to a measured base at Calcutta.

Captain Everest, during his long stay in England, had usefully employed his time in investigating the latest improvements in the manufacture of all classes of instruments and apparatus used in survey operations, and in studying the English Ordnance Survey system. By the liberality of the Honourable Court of Directors of the East India Company, he was able, before his return to India, to provide himself with a full and complete equipment of the most improved and perfect apparatus existent at that time. One of the most important of these improvements was a new device for the measurement of base-lines, which had been already employed on the Ordnance Survey in England, and which was the invention of Colonel Colby of the Irish Survey.

The principal source of error entailed by the use of the old steel chain method of measurement, was the practical impossibility of arriving at the true correction for alterations in the length of the chain due to changes of temperature whilst in use. Colonel Colby's invention obviated this difficulty by making the measure itself self-correcting for temperature. Bars, each 10 feet long, were used instead of chains, each bar being com-

posite,—that is, made up of two strips, one of iron and one of brass, laid one upon the other, and firmly joined together in the middle, so that movements of expansion and contraction would take place evenly at the two extremities.

At a temperature of 62°, the two component metals are of the same length, but owing to the greater expansion of brass as compared with iron, under the influence of heat, at all other temperatures the extreme length of one strip exceeds that of its fellow. Accordingly at the two ends of each brass and iron strip there are projecting pivots, adjusted to a flat movable tongue or lever, which tongue becomes inclined inwards or outwards in proportion as the length of the strips vary. It will thus be seen that there are points on the movable tongues at either end—outside the pivot—which will be the central points around which the movement takes place, and which will be always equidistant from each other. These equidistant points are each marked with a dot; the distance apart of the dots being fixed at exactly 10 feet. The bars are mounted on brass rollers, and are enclosed in long wooden coffers, or boxes, from the ends of which the tongues only project.

Provided with six sets of Colby's compensation bars, and a full supply of every description of improved instrument and apparatus, which the most skilful artificers of the day could produce, Colonel Everest reached India in 1830, having in the meantime been appointed by the Court of Directors 'Surveyor-General of India' in addition to his duties as Superintendent of the Trigonometrical Survey.

On his arrival he determined to measure the base of verification for the 'Calcutta longitudinal series,' with the new measuring bars. A line 6½ miles in length was laid out along the road from Government House, Calcutta, to Barrackpore, at the ends of which two towers, each 75 feet high, were constructed. This base, the first measured in India with the improved apparatus, was measured at the end of the year 1831 and beginning of the year 1832. About the middle of the same year the triangulation of the 'Calcutta longitudinal series,' which had thus occupied over six years, was closed in upon it.

Owing to the defective state of the instruments employed, and other causes, the work on this series was not considered to

be of the first order, and subsequently much of it was again gone over. For a period of about seven years work on the 'great arc series' had thus been entirely suspended, but from this time it was resumed and carried on unremittingly, until this great chain of triangulation, extending from Cape Comorin to the Himalayas, and forming the main axis of the Trigonometrical Survey of India, was finally completed.

Up to the Sironj base the surveyors had worked over a general hilly or undulating country abounding in elevations, affording excellent sites for observing stations, but for a great portion of the distance northward of the Sironj base the work had to be carried over extensive low-lying plains, thickly interspersed with groves of lofty trees, often interposing dense and impenetrable obstacles to the view, whilst the clouds of dust so common during the dry season in the Gangetic valley, rendered the instrumental work exceptionally difficult. Much of the work had to be done at intervals during the unhealthy rainy season, so as to have the advantage of a clearer atmosphere, but this occasioned much loss of health and life to the survey parties. In order to gain the necessary elevation above the plains numerous permanent towers had to be constructed, and great preliminary labour was entailed, not only in the building, but in fixing the position of these towers. So great was their distance apart, that special and complicated signalling arrangements, both for day and for night signalling, had to be devised and elaborated. The towers, of which there were seventeen in all, were 50 feet high, with walls 5 feet thick at the base and 2 feet at the top: they were provided with a stage and awning for the observer, kept detached from the central stone platform on which the instrument rested, so as to avoid vibration.

In the meantime a site was required for the northern base and terminal point of the 'great arc series.' The position finally chosen was in latitude 29° 30′, in the midst of the beautiful Dehra Doon Valley, between the lower Sewalik range of hills and the Himalayas, at a part of it situated about 2000 feet above the level of the sea. The base was most carefully measured with the Colby apparatus during the cold season of 1834-35, its length being 7·42 miles. It was then transferred by means of triangulation to certain peaks of the Sewalik range,

visible both from the measured line and from the valley of the Ganges.

By the early part of the year 1837 the Dehra Doon base-line was connected with the triangles brought up from Sironj; but Colonel Everest did not consider the results altogether satisfactory. The Sironj base had been measured in 1824 by the old steel chain method, and it was now determined to re-measure it with the compensation bars. This was done during the cold season of the year 1837-38, and its length was found to be too short by nearly 3 feet. In 1838 a party was sent to revise all the angles southward of Sironj as far as Beder, a distance of 260 miles, with the new and improved instruments brought out from England by Colonel Everest. This work was completed by the year 1839. On the first connection of the old Sironj and the new Dehra Doon bases, the difference of the measured and computed lengths amounted to nearly 3½ feet. In the earlier days of the survey this would have been considered a sufficiently satisfactory agreement, seeing that the length of the base is nearly 7½ miles, and the distance between the two bases upwards of 400 miles. After the re-measurement, however, of the Sironj base with the same apparatus as used at Dehra Doon, the difference between the length of the latter base, as measured, and as computed through the triangulation brought up from Sironj, amounted to 7·2 *inches* only, a degree of accuracy showing the great exactness of the instruments now employed, and the skill with which the work had been carried on.

In 1841 the old base-line, nearly 8 miles in length at Beder, was also re-measured, and the difference in length as now found, and as found by computation from the Sironj base, was 4·296 inches. Two observatories were established, one at Kaliana, near the Sewalik range of hills, and the other at Kalianpur, near Sironj, both on the same meridian. The difference of latitude between these observatories was exactly fixed by the—as nearly as possible—simultaneous observation of 36 stars, half of them to the northward and the other half to the southward of the zenith of both stations. In a similar manner the exact latitude of a point on the same meridian near the Beder base-line was fixed.

Thus, in the year 1841, nearly forty years after it was com-

menced, were brought to conclusion the operations on the great central meridional arc of the Indian survey, an arc of the earth's surface 1540 miles long, and comprising an area of triangulation of nearly 57,000 square miles (including the revision of the section from Beder to Sironj). At this date the length between Cape Comorin and the Beder base line was founded on Colonel Lambton's early work, done with instrumental appliances far less perfect than that with which the more northern portion of the 'great arc series' had been executed. Some twenty-five years later, the old bases at Bangalore, and at Cape Comorin—or rather other bases on ground selected near them—were measured with the Colby apparatus, and the whole of Colonel Lambton's southern portion of the arc series underwent careful revision.

In the year 1841 the longitudinal series, starting from the Beder base towards Bombay, which had been commenced in 1822 by Colonel Everest, before Colonel Lambton's death, and which had been interrupted, was also completed. The chain extends a distance of 315 miles to Bombay, having an area of triangulation of 15,198 square miles.

We do not propose to follow in detail—or in order of time—the execution of the various meridional and longitudinal ranges of triangles laid down by the Indian Trigonometrical Survey. We will confine ourselves to the main framework only, which will be briefly indicated. Colonel Everest, in consequence of severe illness, was compelled to retire from his arduous duties in 1843, and five years before his death, which occurred in 1866, he received the order of knighthood. In laying down his original programme for the future operations of the Trigonometrical Survey, he abandoned the old network system employed by Colonel Lambton in Southern India, and substituted the 'gridiron' system. He proposed to lay down a number of 'meridional arcs,' or north and south chains of triangles, at close intervals, to be connected by comparatively few cross or longitudinal chains, thus forming sections somewhat resembling a gridiron in shape. It had been originally intended that the north and south ranges of triangulation should be placed at about 1 degree apart, and in that portion of the survey which is called the 'North-east quadrilateral,' or that portion lying

between the 'Calcutta longitudinal series' and the Himalayas, north and south chains about this distance apart have in fact been laid down (see Map of the Triangulation); but in the other main divisions of the survey it has been found unnecessary for topographical and detail purposes to range them so closely together.

Shortly after Colonel Everest's departure from India, the 'Calcutta meridional series,' starting from the base measured at Calcutta in 1832, was carried northwards for a length of 260 miles, over a flat and marshy country, necessitating the building of towers for every observing station, to Sonakoda, near the foot of the Darjeeling mountains. This series, comprising an area of 4136 square miles, forms the eastern boundary of the 'North-east quadrilateral,' and it was completed in the year 1848. The North-eastern or 'Himalayan' series, forming the northern boundary of the same quadrilateral, extends from Dehra Doon to the Sonakoda base, along the foot of the hills, over a distance of 690 miles.

The work on it was executed by different parties, at various times, and its execution was attended with greater dangers and difficulties than had been experienced on any other part of the survey. The operations had to be carried on over one of the most deadly tracts of swamp and jungle in the world, or that forming the renowned 'Terai,' lying along the foot of the Himalayan range. Of the five officers who were engaged upon it, two died from fever, and two were forced to retire utterly broken down in constitution, and it is stated that in one season the lives of no less than forty native employées were sacrificed.

In the year 1847-48 a base-line was measured at Sonakoda for the verification, both of the 'Calcutta meridional' and of the 'North-eastern Himalayan' series, the base serving also as a point of departure for the future prolongation of the work in the direction of Assam. It was measured with the Colby apparatus, and was also proved by a minor triangulation laid off from its side, with satisfactory results.

The 'North-eastern Himalayan series' connects the northern ends, and verifies the series of meridional chains, nearly one degree apart, which at different times were carried up from the 'Calcutta longitudinal series,' and it also completes the

outer framework of Colonel Everest's North-eastern gridiron, or quadrilateral.

From this series a number of observations to determine the distance and altitude of most of the great snow-clad peaks of the Himalayas, including some of the loftiest mountains in the world, were undertaken. Amongst these was one since named 'Mount Everest,' after the late chief of the survey, 29,002 feet above the sea.

In the year 1845 the long 'East coast series,' starting from the Calcutta base, and skirting the coast as far as Madras, was commenced. Progress on it was very slow, and the work was frequently interrupted, especially in the low-lying and difficult tracts between Calcutta and Balasore. Here during the cold season fogs are frequent, and in the spring and hot season the district is the playground of furious cyclones and hurricanes, often causing the most frightful devastation. In one season the tent equipage of the survey party was completely annihilated. The country, for the most part covered with dense vegetation, and low marsh lands, cut up by deep sea creeks, opposed constant obstacles to the progress of the survey. In addition to these physical difficulties, the extreme unhealthiness of the tract was such, that every season the whole party was more or less decimated, broken up, and compelled to suspend operations. The 'South Konkan series,' commencing at Bombay and extending southwards along the West coast, had been taken up after the completion of the 'Bombay longitudinal series,' and was carried down to the neighbourhood of Goa, in latitude 16°. In 1847-48, two important series were commenced, which were to form the northern and southern sides of the 'great North-west quadrilateral.' One of these was to extend from the Dehra Doon base along the foot of the hills to Peshawur, the other was a prolongation in a westerly direction of the 'Calcutta longitudinal series' from Sironj to Karachi, to be called the 'Western longitudinal series,' making one great cross line of triangulation from Calcutta to Karachi, and intersecting at right angles the 'great meridional arc' series at Sironj.

CHAPTER IV

Review of progress by Superintendent of Survey—Area and Cost—Duties of officers, and rate of working—Trigonometrical triangulation the permanent basis for present and future surveys—North-Western Quadrilateral—North-Western Himalayan series—Western longitudinal series—The 'Thur,' or desert of Guzerat—Terminal bases at Attock and Karachi—Indus Valley series—Base at Vizagapatam—Accuracy of survey operations—Extension of East Coast Series—Joining in at Madras—Interior connecting series of chains—Completion of main system of triangulation—Topographical and detailed surveys—Number and position of measured bases—Subsidiary operations—Trigonometrical levelling—Levelling with spirit level and staves—Indus valley line of levels—Extreme care and accuracy—Levelling extended to Calcutta—Various connections with coast—Tidal gauges—Size and figure of the earth—Early Greek measurements—Mohammedan attempts—French arc-measurements—Pendulum operations—Manner of registering number of vibrations—Conclusion.

The superintendent of the survey reviewing its progress from the commencement in 1802 by Colonel Lambton, up to the year 1848 says, 'The grand total area triangulated amounts to 477,044 square miles, and the grand total cost to Rs.34,12,787 or say £312,389, showing an average cost of Rs.7. 2. 5. per square mile, or about 13s. 1d., which cannot but be considered remarkably moderate, especially when the nature of the country and the climate, as well as the absence of all the usual resources to be found in Europe, are taken into account. The hardships and exposure of surveyors working in the field for the greater part of the year in such a climate as India are either little known or little appreciated.' . . . 'The duties of the Trigonometrical Survey are often unremitting day and night, because the best observations are obtained during the nocturnal hours, when the dust raised by the hot wind subsides, and the atmosphere becomes clear and calm. With regard to the rate of progress, much depends on the efficiency of the officers, and on the accidents of the climate. In a hilly country the average advance made per season by each party is about 120 miles in length by 30 in

breadth, or say 3600 square miles. In a flat country the average is 80 miles in length by 12 in breadth, or about 1000 square miles.' And summing up his review he says, 'The triangulation supplies a permanent and accurate basis for the present as well as for the future internal surveys, for it must be borne in mind that as the resources of the country become developed under the fostering protection of British rule, the topographical aspect of many districts must in a moderate number of years be completely changed. Tracts now covered with jungle will be reclaimed. Canals will be dug, marshes drained, and roads established. New towns and villages will arise, fresh groves be planted, and rivers will change their course. That these views are not chimerical may be attested by experience, for places where the tiger, the bear, and the boar were formerly hunted are now covered with fields yielding a plentiful harvest to the cultivator. The greatest difference is also perceptible in the extension of towns and villages, showing the increase of productive wealth which is taking place on all sides. This alteration cannot but produce in the course of time considerable changes in the topographical features of the country, for which reason revised surveys will be required, and these, like the present ones, will be based on the operations of the great trigonometrical system of India, which are intended to form a lasting monument for future generations, and an imperishable record of the landmarks of the present time.'

The programme to be carried out on the North-western side of the 'great arc' was the formation of a great framework for a gridiron to be called the 'North-west quadrilateral' with measured bases at each of its four corners. Just as the 'North-east' quadrilateral has its four measured bases, viz., at Sironj, Dehra Doon, Sonakoda, and Calcutta, so that on the North-West would be dependent on four measured bases of origin and verification at Sironj, Dehra Doon, Attock, and Karachi. The four sides of the new quadrilateral are bounded: On the east by the portion of the 'great arc series' lying between Sironj and Dehra Doon; on the south by the 'Western longitudinal series;' on the north by the 'North-western Himalayan series;' and on the west by a long chain carried up the valley of the Indus from Karachi to Attock.

The 'North-western Himalayan series' from Dehra Doon to Attock was completed in the year 1853. Its length is 416 miles and it comprises 33,000 square miles of very hilly country. It had been commenced in 1847, but its progress was interrupted by disturbed political conditions. The 'Western longitudinal series' extending from the Sironj base to Karachi, was commenced in 1848, and the triangulation reached Karachi at the end of the year 1852, after five seasons of extremely arduous labour. The length of this side of the great quadrilateral is 668 miles, covering an area of 20,323 square miles. A portion of the survey crosses the 'Thur' or desert country north of Guzerat, and its execution entailed much skilful arrangement and forethought for the due provision of supplies and water to the working parties, numbering about 200 persons.

As soon as these two great series were approaching completion it was necessary to measure the terminal bases at Karachi and Attock. A suitable site for the latter was chosen in the 'Chuch' Doab, near Attock, on the east side of the Indus. The valley of Peshawur had at first been proposed as the most appropriate position for this base, but the idea had to be abandoned owing to the disturbed state of the valley at that time, in consequence of the frequent incursions of lawless tribes along the frontier. Attock thus became the upper corner of the North-west quadrilateral and a branch triangulation was subsequently carried to the frontier at Peshawur.

After the measurement of the Attock base the apparatus was sent down to Karachi, and the base-line at that place was carefully measured. The remaining side of the great North-west quadrilateral was to be formed by a long range of triangles extending along the Indus valley from Karachi to Attock. This work was started from both ends of the line, but before it was completed the Sepoy mutiny of 1857 broke out, and work on it was suspended until 1858. It was finally completed in the cold season of the year 1860-61.

In 1862 a base-line 6½ miles long was measured at Vizagapatam, a point on the 'East Coast series,' nearly in the same latitude as Bombay. This base was to serve for the verification of that part of the east coast triangulation lying between Calcutta and Vizagapatam, which had now been completed, and

also for the prolongation from the Beder base of the 'Bombay longitudinal series,' thus completing a range of triangles extending across the Peninsula from coast to coast. At the Vizagapatam base the difference in length, as measured with the compensation bars, and as computed through the triangulation brought down from Calcutta, 480 miles away, was a quarter of an inch only. This great accuracy indicates to what an extreme state of precision all the operations of the Survey had now been brought.

In 1864 the extension of the 'East Coast series' from Vizagapatam to Madras was completed. Thus after an interval of sixty-two years the triangulation which had been started by Colonel Lambton from a base-line at Madras was again brought back to that point, having in the meantime made the long circuit *viâ* Bangalore, Sironj, Calcutta, and the East Coast. During the course of execution of the main framework of the triangulation now sketched, nearly all the interior connecting series of meridional and longitudinal chains forming the principal gridirons, were at the same time being carried on, and at the period to which we have now arrived the larger portion of the main triangulation was accomplished, although it was not until about the year 1883 that the whole system of chains as shown on the accompanying map was complete. Since that period the principal operations have extended eastwards into Burma, and westwards to the borders of Baluchistan and Afghanistan.

The long arms of the all-embracing triangle have also penetrated on every side into the otherwise inpenetrable heart of the great mountain ranges which separate Hindustan from the rest of Asia, and have measured the distances apart of their various chains, and the heights of their lofty inaccessible peaks. During the progress of the Great Trigonometrical Survey of India, of which we have given the very briefest possible outline, the greater part of the topographical and detailed surveys of the interior—on account of which the triangulation was specially undertaken—have *pari passu* been carried on. The many thousands of aërial triangles which we have depicted reaching from hill-top to hill-top, or from tower to tower, stretching in systematic chains across the country from south

to north, and from east to west—making those gigantic 'grid-irons' of which we have been speaking—form the permanent framework, or skeleton of the real survey. On this framework every detail and every physical feature of the interior topography of the country is—and will under all subsequent changes continue to be—supported, and by it are tied together on our maps in their true relative positions.

The whole trigonometrical system of triangulation in India now rests on ten measured base-lines, all of which have been measured by the bars, self-compensating for temperature. These bases in order are as follows: On the 'great arc,' Cape Comorin, Bangalore, Beder, Sironj, and Dehra Doon. At the eastern extremity of the North-East quadrilateral, Calcutta and Sonakoda. At the western extremity of the North-West quadrilateral, Attock and Karachi, with Vizagapatam on the East coast series. For purposes of symmetry an additional base at Bombay would appear to be wanted, but for the practical purposes of the topographical survey it has not been deemed necessary. Another base-line at Mergui, in Tenasserim, has lately been measured to serve as a base of verification for the Burma coast series, and for a point of fresh departure in the trigonometrical survey of that province.

Before concluding this rapid sketch, it only remains to briefly indicate two of the many subsidiary operations connected with the great survey. It was especially necessary that the exact height of the various base-lines above the level of the sea should be determined. Now there is a method of measuring heights by means of measured vertical angles which is called 'trigonometrical levelling,' but this method, although capable of a high degree of accuracy, is nevertheless inferior to that more general system of carrying forward a line of levels and determining heights, which is executed by means of a spirit level and staves.

In Upper India, where the distances from the sea are very great, it became a matter of much doubt whether the heights as hitherto determined by means of trigonometrical levelling, checked only by barometrical observations, were sufficiently accurate. It was determined therefore to undertake and bring up from the coast a regular series of spirit levels as the only

reliable check to the trigonometrical levelling on which the heights of the various base-lines, and also of the peaks of the Himalayan range, were still dependent. The first line of spirit-levelling was carried up the Indus valley, starting from the tidal gauge at Karachi to the Attock base, and to the Sironj and Dehra Doon base-lines, in order to furnish a precise datum or fixed height above the sea, for subsequent mountain operations, where spirit-levelling would be out of the question, and also to ascertain the exact elevation above the level of the sea of numerous points in Sindh, the Punjab, and North-West Provinces, for the use of the survey, and for the service of the canal and other engineering departments.

The great distance to be levelled, and the absence of any certain check at the end of the line, necessitated extraordinary refinements and minute care in conducting this line of levels. In order that every possible source of error might be eliminated or minimised, it was arranged that three sets of observers should level along the same line of pegs following each other in close order, each using a separate instrument and staves, by this means any important error was at once detected, and to eliminate what is called the 'personal error'—or that error due to personal peculiarities, such as eyesight, in the different observers, an alternating system of observations was instituted, so as to counterbalance as far as possible this, together with certain instrumental errors. On arriving at the Attock base, a distance of over 700 miles from the sea, the difference between the height of a point on that base as given by vertical angles, and as now found by spirit-levelling was 3 feet 2 inches. At Dehra Doon base the difference was 5 feet 1 inch, and at Sironj 2 feet 1 inch. This line of spirit-levelling was afterwards extended along the valley of the Ganges to the sea at Calcutta, thus completing one of the longest lines of continuous levelling up to that time executed, the distance along the line levelled from Karachi to Calcutta being 2200 miles. Subsequently other long lines of spirit-levelling connecting numerous important points of the Trigonometrical Survey with the sea at various parts of the coast have been carried out, and much still remains to be undertaken.

Simultaneously at a number of selected points on the coast,

tidal gauges have been established, and observations regularly recorded to ascertain the true mean sea-level, and furnish a fixed datum, or height of departure, to which all the measured heights over the whole country can be reduced and referred.

On the completion of the measurement of the 'great arc series' extending from Cape Comorin to Dehra Doon, a basis existed for ascertaining the curvature of the earth on that arc by means of astronomical computation. Various attempts to discover the true size and figure of the earth have from time to time been made, commencing from a very early period in the known history of mankind. Although probably not the first attempt of this kind, Eratosthenes, custodian of the great Alexandrian library, attacked the problem about 250 years before the Christian era, between Syene and Alexandria. Some two centuries later Posidonius, an Athenian and Rhodian philosopher, made another attempt between Alexandria and Rhodes, by observing that the bright star Canopus just grazed the horizon at the latter place, whilst at Alexandria it rose 7½ degrees. In each of the above cases the distance between the two points of the earth's surface chosen was estimated, not measured.

The Mohammedan Khalif Al Mamun (A.D. 813-832) having become convinced of the globular form of the earth, gave orders to the astronomers of his time to measure a degree of a great circle on it. On the shores of the Red Sea, in the great plain of Shinar and by the aid of an astrolobe, the height of the pole above the horizon was determined at two stations on the same meridian, exactly one degree apart. The distance between the two stations was measured and found to be 200,000 Hashemite cubits. The general result of these various observations gave for the earth's diameter about 8000 miles, a determination not very far from the truth.

In the year 1527, or just five years after Magellan had for the first time circumnavigated the globe, the first attempt made in Christendom to ascertain the size of the earth, was by Fernel, a French physician, who, observing the elevation of the pole at Paris, went northwards until he came to a place where its height was exactly one degree more. He then measured the intervening distance by registering the number of revolutions

of a wheel, and came to the conclusion that the circumference of the earth was 24,480 Italian miles.

Numerous measures were subsequently made in other countries. One of great accuracy was determined by Picard in France, celebrated as having finally confirmed Newton's theory of universal gravitation. Picard connected two distant points by means of a triangulation, and thus ascertained the length of an arc of the meridian intercepted between them. He then compared the measurement with the difference of the latitudes found by astronomical observations. The two points chosen were situated close to Paris and Amiens, and the zenith distances of δ Cassiopeia determined the latitudes of the two places. Some years later, Picard's observations were extended by the French Academy, and in 1718 measurements were carried out from Dunkirk on the north, to the southern coast of France.

The true figure of the earth, whether it was a perfect globe, or whether it protruded or was flattened at the poles, was not, however, as yet ascertained. In order to determine this point, expeditions were sent by the French Government to measure degrees of the meridian, at the equator and at a point situated as far north as possible. These measurements made in Peru, and in Swedish Lapland, confirmed the oblate, or flattened form of the earth. Among the more recent measurements made in different parts of the world, is the one nearly $12\frac{1}{2}$ degrees long, from Dunkirk to the island of Formentera near Minorca, and the great Indian meridional arc, of which we have been speaking. The modern more accurate observations made to ascertain the true size and figure of the earth have resulted as follows: Equatorial diameter, 7925 English miles. Polar diameter 7899 miles. Difference twenty-six miles. In India, however, as elsewhere, it became desirable that the results should be checked and verified by a further and independent series of observations made by means of pendulum vibrations.

Owing to the flattening of the earth at the poles, the force of gravity on the earth's surface is not everywhere the same; but increases somewhat in proportion to the latitude, from the Equator—where it is least—to the poles, where it is at a maximum. Consequently a pendulum swinging freely, having a certain number of vibrations per minute at the Equator, will have

a quicker rate of vibration at the poles, and at every intermediate point between the Equator and the poles a slightly accelerated rate. By observing, therefore, the exact number of vibrations made, say in twenty-four hours, by a pendulum of fixed length, at various selected points along the great arc, the true figure of the earth along that line could be ascertained.

In the practical carrying out of these observations, however, many refinements became necessary, to eliminate various sources of error. Even to fix the exact rate of vibration of the pendulum in any given time required much elaborate arrangement. The method adopted was the following. The observing pendulum was set up in close proximity to a slightly shorter one attached to an astronomical clock, the clock pendulum being shorter, vibrates at a slightly quicker rate, and gradually gains on the other, until a maximum divergence has been reached. At the end of another interval the two pendulums again approach each other until they exactly coincide. At this instant of time the observing pendulum will have made two vibrations less than the clock, in the interval which can be read off the clock face. The exact rate of the clock being known, the precise number of vibrations made by the observing pendulum in twenty-four hours can be readily calculated. In order to get rid of all disturbing currents of air, the pendulums had to be swung in a vacuum.

The ascertainment of the true figure and density of the earth is by no means a matter of mere curiosity; on the contrary, numerous problems of the highest scientific and practical importance are dependent on its correct definition.

The extraordinary value, accuracy, and precision which characterises the operations of the Great Indian Trigonometrical Survey, together with the numerous other scientific labours carried out in connection with it during the present century, under the direction of the British Government in India, has been sufficiently attested by the highest authorities of Europe, whilst the skill and energy with which the work has been accomplished can only be fully appreciated by those who are specially acquainted with the extremely adverse conditions under which it has been carried on.

The present brief and mere outline sketch of these vast

operations conveys but a most fragmentary and inadequate picture of the enormous amount of labour, whether in the field or in the office, which the Great Trigonometrical Survey of India has imposed. To recount the exceptional difficulties and obstacles, physical, political, and climatic, which have been encountered and successfully overcome during the progress of this great work, would alone require a volume. Such a record would exhibit one of the highest triumphs of British energy anywhere displayed. It would depict the arduous toil with which, in furtherance of its main object, the labour was carried on over some of the widest and most deadly tracts of swamp, forest, or desert, perhaps anywhere to be found, and it would paint a deplorable loss of human life. In the course of its long progress we should see the almost impassable and most stupendous mountain barrier in the world conquered and laid bare to its innermost recesses. We should see the signal-stations of the survey planted triumphantly on lofty snow-clad peaks never before trodden by the foot of man, and covering enormous hilly tracts of primeval jungle, unoccupied by, and almost inaccessible to, human beings. Finally, we should witness the patient and skilful exactness with which all the vast stores of data, and information, so laboriously collected, is collated, and the immense chains of triangles are computed and slowly pieced together in the computing and drawing offices of the survey, until there results the perfection of that great skeleton framework, on which is moulded in minute and accurate detail the topographical features of considerably over a million square miles of the earth's surface.

Note.—The data for this very condensed account of the Great Indian Trigonometrical Survey, have been largely derived from the memoranda on the Indian Surveys by Clements Markham (1878) and C. and D. Black (1892)—and other official papers and reports.

ROADS IN INDIA

CHAPTER I

HISTORICAL—NATIVE WORKS—PRINCIPLES OF CONSTRUCTION

Roads in Europe—Diversity of character of Indian roads—Devious routes of natural trade tracks—Roads under the Moguls—Old bridges—Bridge over the Gumti at Jaunpore—Northern Road from Lahore by Shir Shah—'Pepul putta ka Seran,' Jagganath to Delhi—Ancient road bridge and aqueduct in Mysore—Old native road in Assam—Caravanserais—Backward state of roads in early days of English rule—Lord Elphinstone proposes roads for Madras—Inauguration of reform under Lord William Bentinck—Observations on laying out and constructing roads—First-class roads—Hill roads—Laying out—Deviations and moderate curvature—Earthworks—Borrow pits—Openings for culverts and small bridges—Waterway and bridges—Selection and consolidation of road metal—Varieties of material, and modes of application—Binding material—Ramming and rolling road metal—Trees on road-sides—Rest-houses and staging bungalows.

ROADS in the modern sense, that is to say, embanked lines of way, well drained, with easy inclinations and hard smooth surfaces, allowing the use of wheeled traffic with a minimum of resistance, and carried by means of raised bridges over the water-courses of a country, were practically unknown in India, until a comparatively very recent period. In Europe public roads may be classed under two heads, viz., main leading or 'turnpike' roads, and cross-country roads. There is seldom any difference between these two classes, except that the main roads have a greater surface width, and easier gradients than the secondary class: both are metalled and bridged throughout. In India, how-

ever, there is a far greater diversity of character in the public highways. Like the main or 'turnpike' road of England, the first-class Indian road is embanked, is of ample width, well-graded, drained, and everywhere metalled and bridged. The second-class road is also embanked, of the same, or of a smaller width of road-bed, is drained, metalled on the surface, but not yet, or only partially bridged. Or again, a second-class road may be embanked out of reach of floods, and drained, but neither metalled nor bridged, often having, however, permanent causeways, temporary bridges, or other facilities for assisting traction across the beds of the water-courses during the dry season of the year. These second-class varieties of roads may be either virtually first-class highways in a state of transition, or may be intended to remain permanently as designed and made. Still lower in the scale are the surface tracks of more than one kind, usually called 'fair-weather roads.' In the better class of fair-weather road the course is systematically laid out over a selected line of country. For a width of from 30 to 50 feet the surface is cleared of jungle-growth or other obstructions, ditches on either side are cut to serve as drains, and the earth from these ditches is thrown into the centre to level up the worst hollows and inequalities of the ground, and to assist the water to run off into the side drains; or in very low ground a slight continuous embankment may be thrown up. The banks of the larger and more troublesome streams are cut down to an easy slope, so that carts may pass over the bed of the river, either directly, if the bed is firm, or by the aid of some temporary or even permanent causeway laid over the worst portions. During eight or nine months of the year, or even longer in certain districts, these inexpensive fair-weather roads are of great service. Other fair-weather tracks are formed by merely clearing the surface of jungle-growth, and easing the approaches to the beds of the intervening streams, without drains or earthworks of any kind. Other tracks are almost unaided by any labour whatsoever, the traffic, very much as a natural stream of water might do, wearing for itself a passage along the easiest and least resisting line of country.

During the dry season, when, in the plains of northern India, or on the elevated plateaux of the Deccan, the surface soil is

baked and hardened under a fierce tropical sun, wheeled traffic is rendered possible along deviating and tortuous lines of route, often covering very wide stretches of country, with no expenditure of money or skill, beyond the occasional easing down of some trifling natural obstacle, such as the bank of an intervening stream too steep to admit of unaided passage, or the felling and removal of a few shrubs or trees. Such surface trade tracks —often of great width and deeply fissured with heavy ruts, scarcely visible, however, through the thick coating of fine impalpable dust--used for the transit during the dry season of merchandise carried on the backs of pack animals, or in rude carts drawn by yokes of bullocks, served probably for untold centuries all the requirements of the internal carrying trade of the country, and even still forms a not inconsiderable portion of the country's highways. In many of the more undulating and hilly districts in the central portions of India, the extraordinary devious course taken by some of these well-worn trade-tracks, often evidences in a very striking way, the complete apathy of the earlier population, and their neglect of all considerations of convenience and economy, as well as their want of ordinary attention to the physical configuration of the country. Not seldom, it may be remarked that a few hours' labour would remove some trifling obstacle in the direct line of route, and obviate an enormous actual deviation. At other times it will be observed that in order to cross a small stream at some point where the naturally shelving banks afford an easy descent, a track will be found to deviate a dozen miles, which the artificial easing of the nearer banks in the direct line would, by a few hours' work, have obviated, and this where the natural ford is equal to the one chosen, or even more favourable. The practical and energetic European, however, soon ceases to wonder at these things—recognising that he is in a new world, where time is of no value, and where it is every one's duty literally to follow closely in the footsteps of his immediate predecessor.

The general course followed by these natural trade-tracks, existing within small limits of deviation probably for ages—especially in those parts of the country outside the great plain districts of Upper India—were considered by many unreflecting persons to point out, as if under an infallible law of natural

selection, the best possible lines of route for permanent road construction. Nothing, however, could be more fallacious than such an idea—an idea which has, nevertheless, been the cause of more or less costly mistakes. In India, what may be called the natural flow of wheeled traffic unassisted by art, follows, as a matter of course, the—to it—easiest line of country, but it is only the easiest unassisted line. A very little examination of the country usually serves to show that the removal of a few comparatively small obstacles will often to a prodigious extent shorten and cheapen a natural track between two points distant a great many miles from each other. In the earlier days of English road-making in India, when as a matter of necessity the work had to be largely projected and executed by unskilled agency—even such an obvious consideration as the above was sometimes overlooked.

It is very doubtful whether the Mogul Emperors devoted much money or consideration to the question of permanent roads. Very little evidence of such exists at the present day, and, in any case, it is certain that on no single line of traffic was communication open except during the dry season. Many of the minor streams near the larger cities of Upper India were indeed bridged by the Moguls. Some of these bridges have no doubt been carried away, and all trace of their former existence has been long lost. Such as remain are singular structures, not, however, unlike many of the older bridges in Europe. They consist of what at first appears to be a massive barrier or dam of masonry or brickwork, perforated with numerous small pointed-arched openings, often of very irregular size, and affording an open area for the passage of the water, greatly less than the area of obstruction presented by the piers. The whole bridge is usually founded on small wells supporting a continuous masonry platform, and it is to the latter circumstance that those which remain standing have so long withstood the violent floods to which they have so often been exposed. No doubt in many instances these bridges were left isolated, and were dangerous or impossible to approach during the flood seasons, and the bridges themselves have been preserved by the extensive washing away of their approach banks. An interesting and picturesque example of these Mohammedan structures is the old bridge over the Goomti at Jaunpore, of which an illustration is

Goomtee Bridge Jaunpur.

given. This really extraordinary bridge has successfully withstood the floods of centuries, and has probably often been buried beneath the waters. Even so late as the year 1871, ten feet of water passed over the roadway, carrying away all the shops that then existed on the piers. In the Panjab from Lahore northwards, the general direction of a road made by Shir Shah in 1540 can still be traced by the rows of ancient trees and brick pillars at intervals of two miles. The road appears to have followed the natural level of the ground, and was neither metalled nor drained. It was, however, partially bridged. Some of the bridges still remain, and others no doubt have perished, leaving no trace. Remains of ancient made roads are to be found in Bengal, which show that the former rulers of the country were not altogether unmindful of their advantages. One called the 'Pepul putta ka Seran,' lined with Pepul trees on each side, extended a thousand miles from Jaganath to Delhi. This road was from 60 to 70 feet broad. It was embanked over low ground, but was unmetalled. In several places it was bridged, the piers being 12 to 14 feet thick, and the arches of the usual narrow pointed form. In Mysore some remains of bridges of still greater antiquity have been noted. One such bridge was constructed over the south branch of the river Kaveri near Seringapatam, probably at a period dating before the usual construction of archwork. A portion of the bridge serves as an aqueduct to convey water from the river to the town. The structure is of the rudest kind. 'Square pillars of granite are cut from the rock, of a sufficient height to rise above the water at highest floods. These are placed upright in rows, as long as the width of the bridge, and distant about 10 feet from each other. They are secured at the bottom by being let into the solid rock, and their tops being cut level, a long stone is laid upon each row. Above these stones others are placed contiguous to each other, and stretching from row to row in the direction of the length of the bridge. The celebrated bridge over the Euphrates at Babylon was constructed on similar principles.[1]

Major Briggs, Superintendent of Works in Assam, reporting on the proposed Assam trunk road in 1863, gives an interesting

[1] Mill's *History of British India.*

account of some old native road works in that province. He says, 'These ancient rulers of Assam fully appreciated the incalculable advantages to the country of intercommunication by land, and restraint upon the incursions of the water. All their roads, "Allees," as they call them, were constructed with this double object, as highways above the line of flood, and as "bunds" (*i.e.* embankments) to control the inundations of their rivers. From above the spot where the Dihong and Dibong join the Brahmaputra, down to the farthest confines of the Kamrup district, relics of their efforts remain, which for bold engineering skill and wonderful contempt of difficulties, deserve to rank with the works of the old Romans. Their lines of road were generally so well chosen as to direction, that if we can only afford to make our roadway as massive as their bold projects require, many portions of their work may be adopted. To unite their efforts with ours, though years roll between us, and to complete, repair, and bring into use, what internecine wars and foreign invasions prevented them from doing, has throughout a long and arduous survey been my constant endeavour.' And again, 'At the same time, in many of the great plains at present subject to partial inundation, the road embankment might be capable of controlling the inundations of the Brahmaputra, and so serve the double purpose of roadway and "bund." This was successfully done by the old rajahs of Assam. When Rajah Rudru Singh, upwards of a hundred years ago, commenced the present "Bor Allee" (great road), also at places called the "Dhodur Allee" (complete road), he designed it to oppose an impenetrable barrier to the floods of the great river, as well as to afford the most direct line of communication between important points of the country. It was never completed, but the portion between Jaipur and Jankana, near Jorpath, about seventy miles, remains to show the stupendous nature of the work. From the height of the embankment it is visible two miles off. The width at top is 35 to 40 feet. Its course is generally perfectly straight, and where there is a bend, the curve is formed with mathematical precision. The trenches are dug with equal regularity and never approach nearer than 100 feet to the road centre. So thoroughly has it reformed the water system of the country, that in one place the whole drain-

age of thirty miles passes through four openings of about 100 feet each, and the sides of these openings have not been eroded by the passage of the waters for more than a century; the estimated area of waterway on a line parallel to this part and farther inland was 718 feet, according to a former survey made; only one of these openings was bridged, as, according to the present tradition, the Bengali architect succeeded too well in pleasing the Rajah, who, fearful of so accomplished a person returning to Bengal, and offering aid to the British Government, caused him to be strangled. The Jorpati people were most solicitous that the line of the "Bor Allee" should be adapted for the trunk road, and predicted the greatest benefit to the country. They thought the adoption of any other line unworthy of so great a Government, when their own Rajahs had successfully constructed a portion of the great road.'

Perhaps the best evidence of attention to a matter of public road convenience to be met with under native rule, is to be found in the Caravansaries. These erections, often of great size, consist of large square or rectangular enclosures, having usually two massive arched gateways or entrances. Along the inside of the enclosure walls are ranged a series of slightly raised chambers or recesses, each large enough to accommodate a man and his horse. The centre of the enclosure is for cattle, and generally contains a public well and drinking trough. The entrances were closed at night and kept guarded. These shelters afforded free protection to travellers and their merchandise. Many are still in use, and are maintained by the English Government.

It is not easy to account for the extremely backward state of road communication for many years succeeding the establishment of English rule over a large portion of India.

About the year 1818, spasmodic efforts appear to have been made to improve the native tracks, and the surplus ferry funds were assigned for this purpose, convict labour being mostly employed. Even so late as the year 1830 it is recorded that 'beyond 20 miles from Calcutta the roads communicating with the principal stations of the Upper Provinces were in no better state than in the time of the Moguls,' and up to at least ten years later, the Government despatches were still carried on men's backs to Agra and Delhi and the North-West Provinces,

at the rate of 3 or 4 miles an hour. The extraordinary neglect with which the subject of improved road communication was treated by the early government of the East India Company, cannot be altogether ascribed to want of funds, as no doubt the money could have been found if the need had been recognised as pressing. The exceedingly low cost of the carriage of produce by the Ganges and other rivers, and over the natural beaten tracks of the country, no doubt prevented attention being strongly directed to the necessity of made roads. It is said that when Lord Elphinstone was appointed Governor of Madras, he proposed the construction on a comprehensive scale of new roads in that Presidency. The idea appeared so ridiculous to men in authority at that time, that a certain member of the council wrote home to England, 'The silly young nobleman actually talks of making roads.' There seems to have been a sort of impression that made roads were a superfluous luxury in India. On one occasion the Government being pressed probably by some enthusiast, sent out circulars, inviting the various district collectors to send in a statement of what district roads they considered necessary to develop the resources of the country. There is a story current that, in reply to this circular, an ingenious collector reported that 'no roads were required' in his district, 'because the people there did not use carts, but carried everything in panniers on the backs of bullocks.' In course of time, however, it came to be more generally recognised that main lines of metalled and bridged public roads—offering facilities for the transport on wheels of mails and military baggage—were among the first necessities of the State, and that an improved condition of the commercial roads of the country, to lower the cost of produce, was an essential antecedent to all progress. It is to Lord William Bentinck (1828-1835) that the first inauguration of reform in this matter of public road construction is to be attributed, and it was during his administration that the first important steps were taken for the construction of a permanent high road, for military and commercial purposes, to connect Calcutta with the distant stations in the Upper Provinces.[1]

[1] *Vide* 'Public Works in the Bengal Presidency,' vol. xvii. *Proc. Inst. of Civil Engineers.*

Before, however, referring to that early example of Indian road construction known as the 'Grand Trunk Road,' now extending 1500 miles from Calcutta to Peshawar, it will be convenient to make a few observations on some of the more simple elements and principles of road engineering in India, for the benefit of the unprofessional reader.

The selection of a suitable line for a first-class road, even in a moderately level country, is a matter requiring some professional aptitude and skill, and in a mountainous or hilly country a very high degree of engineering proficiency, combined with a keen and practised talent for rapidly detecting the framework of mountainous masses, and the conformation of the valley systems to be dealt with, so as to avoid losing the advantages of elevation, regularly gained. A badly laid out hill road may impose the lifting of the whole weight of traffic to a height far beyond the total altitude to be actually surmounted, whilst a good line will continue its course at an almost uniform and easy slope, losing scarcely anything by descent. The laying out of a line of first-class road over a tolerably level plain district is a comparatively simple matter, but even here, the choice of country within certain practical limits of deviation requires intelligent co-ordination of means to ends. It will not suffice to take a ruler, and, on the map, draw a straight line from one point to another. In the first place, the cost of 'metalling,' that is, placing hard material for the wearing surface of the road, will cost maybe six to eight times as much as the cost of earthworks, and after the road is made, the 'metal' has to be periodically renewed as worn down by the traffic; hence the neighbourhood of quarries, where stone metal can be obtained, or the facilities for obtaining other kinds of metal used in road making—such as that concretion of carbonate of lime in hard nodules called in India *kunka*, or gravel, or even hard burnt broken brick and sand, have to enter into calculation, so that it may be decided how far it will pay to sacrifice the absolutely shortest line for the sake of cheapening the carriage of the most expensive items of construction and maintenance. Again, to avoid exceptionally expensive bridgework, it will be often economical to keep the road on the ridges of a country, involving some deviation, or merely favourable points for crossing

the larger streams, causing a less expenditure in bridge foundations, and may warrant a more or less degree of departure from the shortest line. Even where no money saving is to be gained by leaving that perfectly straight line, which is of course the least distance between any two points, it is better to deviate a little. There is perhaps nothing in the world more monotonous or fatiguing than a perfectly straight and level road, always stretching away to distant points on either horizon. Moderate curvature adds but the merest trifle to the total length, and anything more than two or three miles of perfectly straight line ought to be avoided.

The road being laid out, and levels taken at some 300 or 400 feet apart, on stout pegs driven into the ground along the centre line, the heights and quantities of the earthworks required can be estimated as soon as the width of the road has been fixed, and bamboos or stakes are driven so that their tops, or cross pieces fastened on them, shall mark the future road surface; a trifle of extra height being allowed for the subsequent settlement of the earthwork. The earth to form the embankment, usually only two or three feet high in a plain country, but of course varying in height where inequalities of surface level exist, is obtained from 'borrow' pits dug along the sides of the road and parallel to its course. These borrow pits do not form a continuous excavation, because almost every country has some slope, and if they were continuous water would run along them, forming streams which would wear away their sides. The pits are, therefore, not longer than about 100 feet each, having spaces of untouched ground of about fifty or sixty feet—or even more if the soil is very loose—between them. Their sides are sloped, and they are made wide enough to admit of the necessary quantity of earth being got out of them, without the necessity of digging more than a few feet in depth. It is usual to keep them thus shallow so that they may be used for obtaining earth for the future repair of the banks, but here and there some are made deep enough to retain a certain amount of water, which is always required in renewing or mending the surface of the metal. The near edge of the pits are always placed at some distance from the bottom of the embankment slopes.

Generally at the lowest points of the ground section, along the line of the road, it is necessary to leave openings for culverts or small bridges, to allow the cross drainage of the country to pass from one side of the road to the other. Money can often be saved by cutting drains from some of these depressions, so as to divert any water collected, and lead it to still lower depressions, so as to collect the cross drainage as far as possible into a fewer number of separate culverts, although these may individually require to be a trifle larger. To make these small bridges for cross drainage just large enough but yet not too large and expensive, is often the most important of the minor problems to be solved. In some cases the separate drainage basins, or collecting areas, on the up-stream side of the road bank are easy to determine, so that the maximum rainfall of the district being known, the total amount of water to be provided for can be readily ascertained. In the case of large streams or rivers, however, especially if liable to receive the surplus or 'spill' water from other still larger courses, the proper amount of waterway to allow becomes a more intricate problem, and in most cases it will be better to err a little on the safe side than to run any great risk. If the bed of the river to be bridged is very hard and not liable to be washed or scoured out by the water, so as to undermine and injure foundations, or if the bridge is built with a solid masonry platform between the piers and abutments, protected along the up and down-stream edges by walls carried well down into the river bed, so that the force of the current will not be able to wash it up, the water can be safely allowed to rise to a greater height by keeping the bridge shorter in length than might be otherwise necessary. In this particular there will of course be every degree of difference or difficulty, accordingly as small channels or great and wide rivers are dealt with.

Another exceedingly important matter in connection with road-making is the selection and consolidation of the hard material which is to form the wearing surface of the road. It is always usual to wait until the earth forming the banks has become thoroughly hardened and compacted together under the influence of the rainfall, before placing the expensive road-metal upon it, otherwise a great deal more will be required,

which, although in the end not detrimental to the road, will render it much more costly. It is also generally economical and necessary to interpose between the earthwork of the banks, and the expensive hard road-metal, some intermediate substance, such as one or other of the various forms of decomposed material called *moorum*, gravel, broken rubble or rough stone —or even broken brickbats—ordinary river sand mixed with many kinds of soil, especially that known as 'black cotton,' will also harden the surface of banks to a surprising degree. The varieties of substances used for metalling the surface of roads in India are very great. One of the commonest, in the districts where it is abundant, is hard nodular *kunka*. It makes an excellent, although in dry weather a very dusty road, besides requiring a good deal of petty repair under exposure to heavy traffic. Block *kunka*, besides being expensive to break unless quite fresh from the quarry, is inferior, and is seldom employed. All the softer materials, such as broken laterite, and most varieties of globular trap, or the hardest kinds of broken bricks, etc., are ill-adapted to form a durable road surface, but have often to be employed where better are not procurable. As a general rule, the softer the material, the larger is the average size of the pieces into which it is broken, so as to give a greater section of resistance to fracture under the grinding action of the cart-wheels, the rough bottoming is also made thicker, and the road is formed with a greater rise in the centre. *Moorum* metalling, which is largely used in the Bombay Presidency, is spread at least twelve inches thick, on a good bottom. It makes an excellent dry-weather road, but will not well stand a heavy traffic in the wet season. Globular trap, very common in Malwa, is too friable to make a good road metal. Under traffic the fragments, however angular they may have been when first broken, are apt to wear down at the edges, leaving an unconsolidated mass of rounded stones very difficult to bind together. All the harder granitic and basaltic rocks furnish, when broken into road-metal, the best and most lasting surfaces; they are, however, the most expensive in first cost. When good *moorum* is also plentiful, perhaps the most economical process is to use this material alone as road-metal for some time, until the crust of the

road becomes thoroughly firm and reliable. Thin layers, about three inches thick, of hard stone road-metal can then be gradually applied.

In order to bind the hard stone fragments together some fine sand or *moorum*, in quantity about one fifth the volume of the metal, is required. In using broken basalt, however, much less of this binding material is employed; it takes consequently a far longer time to consolidate into a compact surface than other materials; but when once consolidated it forms one of the most resisting of road surfaces. If too much binding material is used with basalt, or indeed with any other very hard metal, it causes the road to become rough and unpleasant, the softer material, wearing and being blown from the surface by the wind, is apt to leave the upper parts of the less wearable stone fragments projecting. The choice of material for road-metal in India is most commonly limited in each locality to some one or two substances which it is possible to obtain at a reasonable cost. Whatever may be employed, whether hard stone, *kunka*, or *moorum*, it is necessary that it should be artificially compressed into a firm compact crust, so as to be unmovable by the wheels of vehicles. This is usually done by beating it down with heavy rammers by hand labour, or by the frequent hauling over it of heavy rollers. The latter process is, for the harder kinds of metal, by far the best, where really heavy rollers are obtainable. Steam-road rollers of fifteen or twenty tons weight are also frequently and economically used for consolidating road surfaces where a large quantity of such work is required to be done.

On the better classes of Indian roads, lines of trees planted so as to afford a grateful shade to travellers is an almost invariable rule, and groves of trees at about day-journey intervals are frequently added. Near these groves wells are dug to supply both man and beast with a plentiful supply of water, without which, in so dry and thirsty a land, travelling would be virtually impossible. On such roads, also, accommodation and shelter for the upper class of travellers is in all cases provided. 'Rest houses' or 'staging bungalows' are erected at intervals of twelve or fifteen miles along the roads. These provide accommodation for two or more families; containing distinct sets of apartments

plainly furnished. A keeper, who acts also as cook, and supplies provisions under a fixed tariff, together with a small staff of menial servants, is maintained, and a small fee—for the benefit of local or district funds—is charged to travellers for the temporary use of the 'rest-houses.'

CHAPTER II

Neglect of Public roads until comparatively late date—Military fair-weather Roads—Road up the Bhore Ghat early in the century—The Grand Trunk Road—Alignment—Early commencement under Warren Hastings—Real commencement under Lord William Bentinck—General description of Grand Trunk Road—Bridges—Lelajaum Bridge—Paucity of information—Paved Causeways—Sone Causeway—Probable cost of Grand Trunk Road—Difficulties of early engineering work in India—Insufficient waterways—Initial importance of Grand Trunk Road—Other early road operations—Agra to Bombay—Great Deccan Road—Extension of Hill Roads—Coast road through Orissa—General outline of important roads—Indus river at Attock—Proposals for a tunnel—Modified project—Construction of Attock Tunnel—Abandonment of work—Central India Roads—Roads in the Berars—Roads in the Central Provinces—Northern, Eastern, and Sangor Roads—Early importance of Northern road—Important Bridges—Roads in Bombay and Madras.

It has been pointed out that very little was done by the English Government in the matter of public roads for India until a comparatively late date. Fair-weather roads were constructed by, and for the use of, armies on the march, but these were neglected almost as soon as they had fulfilled their immediate purpose, and those absolutely necessary for the control of newly acquired territories were only kept open by constant reconstruction. These military road-tracks were no doubt of service to the commercial traffic of the country, and this especially so in some of the more mountainous districts in the lower peninsula, where work of a much more permanent and substantial character had of necessity to be undertaken from time to time for military purposes, such as that road passable by artillery, made under the orders of the Duke of Wellington in the early part of the century, up the Bhore Ghat between Bombay and Poona. It was not, however, until the years 1840 to 1845 that any large and systematic general construction of

permanent commercial and military roads throughout the country was undertaken.

The earliest example of an important main road constructed in India was a considerable length of that well-known highway 'The Grand Trunk Road.' This remarkable work when completed was no doubt for many years unsurpassed by any single public road then in existence. Owing to various causes work on it was not brought to a final conclusion until long after its first inception and commencement, but a very large portion of it was executed before the year 1848. The Grand Trunk Road now stretches in a practically unbroken line from Calcutta to Peshawur, to within a short ride of the mouth of the Khyber Pass in Afghanistan, a total distance of 1500 miles. Starting from Calcutta the road is taken in an almost direct line to the southern bend of the Ganges near Benares and Mirzapore, passing through the Kymore line of hills forming the last spur of the Vindhyian range of mountains stretching across India. From Mirzapore the road follows the valley of the Ganges to Allahabad and Cawnpore, thence striking somewhat to the west it follows the eastern bank of the Jumna to opposite Agra and Delhi, with which towns it was united by temporary pontoon or boat bridges. Northwards of Delhi it passes *viâ* Karnal, Ludhdiana, Lahore, and Jhilam, crossing the Indus at Attock a few miles before reaching Peshawur.

It is stated that under the government of Warren Hastings, so far back as the years 1772 to 1785, a commencement of this magnificent early work—on that portion of its length lying between Calcutta and Benares—was made by a Captain Charles Rankin, but to what extent, or whether the work executed was anywhere or everywhere on the precise alignment of the present trunk road, does not appear. It is most likely, however, that the very early work referred to would have been the construction of what would now be called a fairweather road of superior class. However this may be, the inauguration of the first important steps towards the realisation of the splendid project of a great permanent trunk road from Calcutta to Delhi and the North-West frontier—afterwards successfully carried to completion—appears to have taken place under the government of Lord William Bentinck 1830 to 1835. Twenty years

later, or in the year 1855, the road was completed to Karnal, some seventy-five miles north of Delhi, or for nearly 1000 miles from Calcutta, and its prolongation to Lahore was then in progress. The extension of the road from Lahore to Peshawur, although a vigorous commencement had been made not long after the annexation of the Panjab, was delayed for many years owing to want of funds.

The Grand Trunk Road has been constructed throughout as an embanked, thoroughly well-drained and well-metalled highway of the first class. It is raised in every part well above the height of known floods or inundations. The top width of the earthwork was in the first instance made 30 feet, but was soon afterwards increased to 40 feet, with side slopes of 4 to 1. The central portion was originally everywhere metalled to a width of 16 feet, with either broken stone or *kunka*, laid 8 inches thick, and rolled or beaten down to a thickness of 6 inches. Rows of good timber trees were planted for the greater part of its enormous length, along the foot of the embankment slopes at intervals of 50 or 60 feet. Halting-places, or encamping-grounds, were also arranged at suitable intervals for the convenience of merchants and goods, and at every ordinary stage for troops on the march, enclosures for shops, and open encamping grounds, marked off and kept clear from cultivation, were established. 'Rest-houses' for the better class of travellers were also provided at distances apart of ten or fifteen miles along the road.

Except in the case of the widest rivers, of the first order of magnitude, the road was permanently bridged throughout. Subsequently, after the construction of the great line of railway —first from Calcutta to Delhi, and then on to Peshawur— provision was made for carrying the road over these largest rivers by means of the great railway bridges then constructed. The bridge structures on the lower portion of the trunk road were to a great extent constructed of stone, the piers being founded on cylindrical wells, or on perforated blocks of brickwork sunk into the sandy beds of the rivers in the manner peculiar to India. A great number of these bridges were of very considerable size—such as the one over the Lelajaum river, consisting of twenty-six arches of fifty feet, costing the

moderate sum of about £10,000. Little detailed information, however, appears to be now available as to these early works. Occasionally, in the case of the large rivers, where bridges, either temporary or permanent, could not be constructed except at inordinate expense, paved causeways across the bed were resorted to. This expedient is often of considerable value in India, where the greater number of the watercourses are dry, or nearly so, for the larger part of the year, and where in many parts of the country they contain practically no water of any consideration for nine or ten months out of the twelve. In such cases the banks of the stream are cut down to an easy slope, and the whole sandy width of the river-bed is traversed by a paving—often of stone set in mortar, resting on a foundation made sufficiently secure to withstand the rush of water during the seasons of flood.

The first large river encountered by the Grand Trunk Road, before reaching Mirzapore, was the Sone, and it was carried over the unusually wide sandy bed of that watercourse by a causeway of the above description, no less than 11,450 feet, or over two miles in length. The paved roadway, 16 feet in width, was formed of stone slabs, 9 feet and 7 feet long, about a foot and a half broad, and 1 foot thick. A foundation was provided by first driving two parallel rows of common jungle-wood piles to a depth of about 15 feet, for the purpose of supporting bamboo frames and mats to temporarily hold up the sides of the sand excavation that was to be made between the two rows of piles. The sand being excavated and a trench dug of the requisite depth and width, a layer of gunny-bags filled with concrete made of river shingle and lime, was set closely packed together over the whole bottom of the trench. On these bags a layer 2 feet 6 inches thick of rubble stone was laid, set in similar concrete, on which the long paving stones forming the causeway were placed crossways in alternate long and short lengths so as to break joint. The joints of the stones were then grouted and pointed with good hydraulic mortar, and the surface of the causeway was finally levelled but left rough enough to afford a secure foothold for draft animals.

It is not possible to state with any accuracy the total cost of the Grand Trunk Road, constructed at intervals over a con-

siderable number of years, and a large proportion of the earlier work being done by convicts, or by famine relief labour. The probable cost of the initial work would hardly be less than £500 a mile, exclusive of the large bridges, or between seven and eight hundred thousand pounds. A sum of £489,100 is recorded to have been spent on it up to the year 1848, at which time the cost of maintaining the road, so far as completed, was £35,000, and for many years subsequently the total cost of maintenance was not less than about £50 a mile. Before the introduction of railways the traffic carried by the trunk road was very large, and it was calculated that the whole thickness of metalling, throughout its entire extent, was renewed every six years.[1]

At the early date when the greater portion of this splendid public work was constructed, English engineers working in India were to a great degree unfamiliar with the peculiarities and flood phenomena of the great Indian rivers, and, moreover, carried on their operations under exceptional difficulties as regards skilled labour of every description. As might be expected, in several instances bridges were constructed with a waterway insufficient to pass without undue obstruction the sudden and violent floods to which they were subjected, and consequent failures occurred. In 1850, during the construction of the Lelajaum bridge above mentioned, a heavy flood carried away five of the arches which had been completed. In another case, owing to insufficient waterway, an entire bridge was wholly destroyed. Delays in construction were also frequent, whether caused by paucity of funds or from one or other of the innumerable difficulties encountered in the manufacture and provision of building materials, and their transport over a virtually roadless country, and the absence for many years of any other than the rudest labour. The early successful achievement of this magnificent 1500 miles of permanent road, and its real magnitude, when considered in connection with the peculiarly difficult conditions under which the main portion of it was carried out, has been to a great extent thrust into the background by the subsequent press of railway construction. Its

[1] *Vide* 'Public Works in the Bengal Presidency,' vol. xvii. *Proc. Inst. Civil Engineers.*

importance as a commercial and military line of communication has also necessarily dwindled beside the splendid iron road which is now placed almost alongside of it for the larger portion of its length, but it remains none the less a truly remarkable and representative monument of early British energy in India, and a work which, for boldness of conception and execution under exceptional conditions, has hardly ever been surpassed.

Other very early road operations that may be mentioned are the following: In the five years succeeding the year 1839 upwards of 400 miles of embanked and partially bridged roads were constructed in the Bareilly district of the North-West Provinces, and seventy-seven bridges of masonry or timber had then been built. In 1840 work was commenced on a great trunk line of road designed to extend from Agra to Bombay—the total length of which is 735 miles. An annual expenditure of £10,000 was at that time apportioned to this work. Before many years, a postal service along the road was established, and, by offering premiums to the postmasters, an average speed of ten miles an hour was obtained between the chief breaks of continuity—the work being performed by light mail-carts. This fine metalled and bridged line of communication now extends from Agra, *viâ* Gwalior, Indore and Mhow, Dhulia, Nasik, and the Thul Ghat, to Bombay. It is mentioned also that up to the year 1851 no less than 638 miles of embanked and partly bridged roads had been constructed in the small district of Azimgurh in the North-West Provinces.

An important trunk line called the 'Great Deccan Road' emanating from the line of the Grand Trunk Road at Mirzapore on the Ganges, to extend *viâ* Rewah to Jubblepore, and connect with Nagpur and Bombay, was also an early work, and in 1856 the bridging and metalling of this great highway, now extending across the whole continent of India, was commenced. By about the year 1870 nearly all the larger undertakings connected with the earlier through trunk routes had been completed, including many of the fine engineering works leading to the Himalayan hill stations, or to communicate with the Tibetan trade routes beyond them; to the coffee districts of Wynaad, and to the Nilgiri hills in the southern peninsula, as well as the long south-western coast road from

Calcutta, through Orissa, *via* Midnapore, Belasore, Cuttack, and Gangam in the Madras Presidency, together with a very large total mileage of secondary roads connecting the main thoroughfares with the railway centres which were then springing rapidly into existence.

Some few of the more important main-lines of first-class roads which have now been opened out may be enumerated, but it would serve no purpose, and be needlessly tedious to attempt any general trace even of these. The reader will gather a better idea of the extent and ramification of the first and second-class roads of India by consulting the annexed map. Many of the roads to be mentioned are now old established highways, such as the Calcutta-Darjeeling road, which, metalled and bridged throughout, over a very difficult and inundated country, and crossing numerous watercourses and several large rivers by iron bridges resting on screw-piles, is carried well into the Northern mountainous district, opening up an important connection with the external trade routes on that side of India. In the low-lying districts of Eastern Bengal an excellent system of water carriage, by the numerous intersecting channels, prevents the necessity of any considerable extension of ordinary roads.

The old and prosperous districts of the North-West Provinces are covered with a very extensive network of roads of every class. From Gwalior, on the Agra road, and from Cawnpore, main trunk lines extend to Jhansi, Laltipur, and on to Saugor in the Central Provinces. From Bareilly, after traversing nearly seventy miles of plain, a mountain-road is carried to the hill sanatoria of Naini Tal, Ranikhet and Almora, and in the elevated district of Gharwal various lines of hill road extend to the Niti pass, forming a valuable line of communication for traders from Tibet.

In the Punjab and upper parts of Scinde a very considerable network of excellent roads also exist, among others the important road from Umballa to Simla, and the Hindustan Tibet hill road extended beyond for over 150 miles up the Sutlej Valley. The Kangra Valley road, and that from Rawalpindi to Murree, and from the same place to Malora and Kohat; the frontier roads—Peshawur to Kohat, Thal, Katabagh, and

Isakhel; from Jhilum and Gujrat to Miani, Shahpur, Jhanj, and Chichawatni, situated on the railway above Mooltan; from Mooltan to Bahawalpur, and Dera Ghazi Khan, and numerous others.

Soon after the Sepoy Mutiny of 1857 serious attention was directed to the military necessity of reducing the difficulty and danger of crossing the river Indus, on the line of the grand trunk road in the neighbourhood of Attock, near the north-west frontier of India. The town and fort of Attock is situated on the left or eastern bank of the Indus, just below the junction of the Cabul river, at a point where the usually wide channel of the first is contracted to 1000 or 1200 feet in its passage through a range of hills which crosses its course. This contraction causes the river to rise in ordinary high floods to the great height of about 50 feet above the average cold season level, the velocity of the current being then increased to upwards of 12 miles an hour. The river, moreover, is subject to extraordinary floods at uncertain intervals, caused by the temporary damming up of one or other of its Himalayan branches by ice or landslips. In the years 1841 and 1858 it is recorded that the summer floods rose 100 and 70 feet respectively, above the ordinary cold weather level, and from the nature of their origin, and the formation of the valley at Attock, there appears to be nothing to prevent the occurrence of still higher floods at any time. The important crossing of the Indus in the neighbourhood of Attock, on the line of the grand trunk road, was for many years effected by means of ferry-boats during the summer, or flood-season, and by a temporary boat-bridge during the winter; the ferry crossing was always difficult and often dangerous, and the communication was at all times liable to sudden and prolonged interruption. Numerous proposals and trial efforts were made from time to time for improving this state of matters—such as a permanent boat bridge, a flying bridge worked by cables and the force of the current, a steam ferry, and a suspension or other bridge placed at a high level above the reach of floods. The great difficulties to be encountered in dealing with such a torrent as the Indus at Attock, subject to so great an ordinary flood rise, and liable, moreover, to extraordinary floods of uncertain

limits, led at length to a well-considered proposal in the year 1859, to turn the more important of these difficulties by the substitution of an under passage or tunnel beneath the river. Careful studies entered into showed that the banks and bed of the Indus at Attock were composed of slate rock, moderately easy to work, and apparently free from fissures likely to seriously endanger, or enhance the cost of the work. A scheme was therefore elaborated in full detail for a brick-lined tunnel 1215 feet long, 24 feet wide, and 20 feet high, to extend underneath the river, with a roadway 82 feet below low-water level. It was proposed that the level of this under passage should be reached by descending tunnelled approaches on either side of the river, each on a grade of 1 in 20; the entrances being placed at 100 feet above the level of winter flow—that is, at 182 feet above the floor of the actual river tunnel. The total length of the complete gallery, including the approach grades, would have been 7215 feet, or over 1⅓ miles. The tunnel was to be ventilated by air shafts placed 600 feet apart (except at the river section, where the interval would be longer) in the shape of hollow cut-water towers, having their summits placed above the reach of floods, and the gallery was to be lighted throughout with oil-gas manufactured on the spot. Duplicate pumping engines were to be provided for keeping the tunnel clear of water, and provision was also made for its rapid flooding by means of a syphon at any time under military necessity. The estimated cost of this project was £104,408.

The scheme so far found favour with the authorities that a sum of £1000 was sanctioned for the purpose of carrying out an experimental trial drift, and in March 1860 the sinking of the necessary shafts on either bank of the river was commenced, by military labour. The leakage of water, however, was found to be heavier than anticipated, and subsequently further sums, amounting in all to £6000, were granted, until, in the summer of the year 1862, it having been found that the cost of the work greatly exceeded the rates of the first rough estimate framed, the Government decided upon a suspension of operations, at a time when only 258 feet remained to complete the junction of the drift-gallery across the river-section.

The drift underneath the river—about 6 feet by 3 feet in

section—and the vertical shafts on either bank were, however, afterwards completed, but the execution of the complete tunnel project was at the time postponed. The work actually carried out was as follows. On the east bank of the river a shaft, 168 feet deep, with 8 feet extra for drainage, was sunk through the hard rock. On the west side a similar shaft—situated 1505 feet 6 inches from the first—was sunk 93 feet deep, with 8 feet extra for drainage. The position of the west shaft being near the river edge, and much below summer water-level, a hollow pier of masonry was built up to keep out the floods. From near the bottom of the shafts two galleries were pierced northwards for a distance of 25 feet, each 6 feet high and 3 feet wide, to meet the main drift of the same dimensions, which was carried under the river, and on the east side of the river at the level of the grand trunk road, a gallery was driven to meet the vertical shaft. Owing to fissures in the rock, and the influx of water, both shafts were lined with brick masonry. The drift-gallery beneath the torrent of the Indus was made with a slope or inclination of 1 in 300 towards the east, or Attock side, in order to drain off the water. The work throughout was performed by a small detachment of the 24th Punjab Infantry, aided and directed by six European miners; the object of the drift heading being to test the nature of the rock, and the feasibility and probable cost of carrying out a complete tunnel scheme.

After some discussion it was decided on various grounds to abandon the tunnel project; it being held that an overhead bridge would be a more suitable crossing, and less costly to maintain. The miners were, therefore, withdrawn, and the heading was allowed to fill with water. In the year 1870—when Lord Mayo, then Governor-General, came to Attock,—the drift-gallery was pumped out for his inspection, and it was found to be quite uninjured. The proposal to complete the work was reconsidered, but it was again rejected in favour of the combined road and railway bridge, which now crosses the Indus at Attock, a remarkably fine work, which will be subsequently fully described. The tunnelling work carried out in 1860-64, was executed with few appliances, and under great financial restrictions, but was sufficient to demonstrate the per-

fect feasibility of constructing a permanent tunnel under the Indus at a reasonable cost. The military importance of a second line of communication removed at least from the danger of any possible injury by extraordinary floods, would appear to indicate the desirableness of completing the Attock tunnel, but the relative value and advantage of the work as compared with other means of passage, either at Attock or elsewhere on the Indus, is one for decision by scientific military experts. The successful piercing of the drift gallery under the river has been here mentioned as a bold and interesting operation, carried out upwards of thirty years ago, by a small and energetic body of pioneers, under very disadvantageous conditions.

In Central India occur the roads *viâ* Jeypore, Tonk, and Deoli, Ajmere, Neemuch, Rutlam, and Mhow. The line communicating with the North-West Provinces, leading from the grand trunk road at Aligarh, *viâ* Muttra, Bhurtpore, Jeypore, Ajmere, Sihari, Mount Aboo, and Deesa. In the Berars is an excellent system of first-class roads intersecting the rich cotton districts, such as the lines Malkapur, Buldwana, and Mehkar, Nandura, Molala, Khamgaon, and Jalna (leading into the Bombay Presidency *viâ* Aurangabad, and Ahmednagar to Poona). Akola to Bassim and Umarkhed, Murtazapur to Karunga and Bassim, Budnera *viâ* Amroati to Morsi and Ellichpore.

In the comparatively late acquired Central Provinces, it is recorded that in the year 1862 there were barely twenty miles of first-class road fully opened out. During the following twelve or fifteen years, besides a very large aggregate mileage of roads of the secondary class, three excellently constructed first-class lines of communication were carried out, viz. the Northern, Eastern, and Saugor roads, together with those from Jubbulpore to Mandla, and from Warora to Chanda. The northern line extends from Nagpur *viâ* Seoni to Jubbulpore, a distance of 185 miles. The eastern road is carried from Nagpur, *viâ* Bhandara and Nandgaon, to Raipur, the chief town of the Chattisgarh district; and to Sambulpur. The road is metalled throughout, and permanently bridged, except over the very largest rivers. The Saugor roads form an important connecting link between Bandalkhand and Western India, these

extend from Jubbulpore, *viâ* Damoh, to Saugor and Hatta, and from Saugor to the valley of the Nerbudda, near Nursingpore. The short line of northern road from Nagpur, *viâ* Seoni to Jubbulpore, is stated, as regards engineering and alignment, to be one of the best in the interior of India. The road has for many years ceased to be of more than local value, but for a considerable time—before the difficult section of railway traversing the Nerbudda valley from Khandwa to Jubbulpore was completed,—this particular length of road formed a very important link in the chain of communication between Upper India and Bombay, inasmuch as it connected the termini of the then open railways situated at Nagpur and Jubbulpore respectively. The road, which is everywhere bridged and metalled, surmounts a portion of the Satpura range of hills by a well laid out and constructed length of mountain-road, with an even line of gradients of 1 in 30. The Seoni plateau is 1500 feet above the level of Nagpur, and until this line of communication was made, all produce from the high lands could only be brought to the larger markets, or to the railway at Nagpur, by means of pack animals. The road also crosses two important rivers, viz., the Kanhan, and the upper portion of the Weingunga; the first by a handsome stone bridge, which is probably the largest bridge for road purposes constructed in India, and, as such, has been selected for more detailed illustration in the following chapter. The bridge over the Weingunga is a fine brick structure, consisting of twelve arches of 50 feet span, placed at a considerable elevation above the river.

The numerous important through lines of first-class roads in the Bombay and Madras Presidencies are now for the most part old-established highways, and later construction, here as elsewhere, has largely consisted of district roads and railway feeders. By the year 1870, 1800 miles of roads, of which upwards of 500 miles were metalled and bridged, are stated to have been constructed in Mysore alone, opening up numerous lines of communication for cart traffic, from the elevated plateaux, down to the principal places on the Western coast.

CHAPTER III

Types of bridges on Indian roads—Early iron suspension bridge near Saugor—Early iron bridge over the Gumti at Lucknow—Particulars of history—Masonry bridges—Examples—The Palamcotta bridge over the Tambrapurni in Tinnevelly—Bridge over the Sohan, Lahore, and Peshawur road—The Kanhan bridge at Kamthi—Description of the Kanhan bridge—Unsuccessful attempt to bridge the river—Construction of the second bridge—Foundations—The Cofferdams—Piers and abutments—Details of timber centerings—Archwork—Method of striking the centres—Particulars and cost of bridge—Paucity of statistical data relating to Indian roads—Probable annual amount expended on roads in India—Conclusion.

It is evident that over the immense mileage of metalled and bridged roads, intersecting in every direction the great continent of India, and traversing such wide tracts of country, covered for the most part with large watercourses and more or less frequent great rivers, an enormous aggregate number of bridges spanning these streams will occur. Moreover there will necessarily exist a general similarity in the type and particulars of such structures. For ordinary road purposes Indian rivers and watercourses of all sizes are commonly crossed by masonry arched bridges of brick or stone, with piers and abutments founded either directly on the hard substratum found at their sites, or on cylindrical wells, or blocks of masonry sunk to a sufficient depth into their sandy beds. Occasionally, although rarely, the superstructure, and even the piers of road bridges may be constructed of iron, or timber—the latter material, however, for climatic reasons, being ill adapted for permanent erections in India. In the few notices or illustrations of Indian road constructions which follow, the particular works mentioned are chosen either on account of special interest as early examples of road engineering, or on account of their more than

average size; from either category the number of works noted might have been enormously increased.

A road work, interesting only from the early date of its construction, and from the circumstance that the whole structure was made up in India, and erected without the aid of skilled workmen, is that of an iron suspension bridge, constructed upwards of fifty years ago, to carry a road over the river Beosi near Saugor in the Central Provinces. The bridge is 200 feet in clear span between the points of suspension, and the abutments, which are built on solid rock found near the surface, are 42 feet high to the roadway. The chain piers carried on the abutments are 33 feet high above the road; the arched passage ways through them being 9 feet wide and 15 feet high. The bridge platform is 200 feet long, 12 feet wide, and weighs, with suspension chains, about fifty-three tons. The iron rod suspension chains are twelve in number, arranged in pairs,—three pairs on either side, one above the other, at a distance of 2 feet apart, they pass over twelve iron rollers a foot in diameter (each weighing about half a hundred weight), placed on the suspension piers, and are firmly anchored into masses of masonry 16 feet below the surface of the road. The twelve main chains are made up of solid round bars $1\frac{1}{2}$ inches in diameter with enlarged eyeholes, and from 15 to $15\frac{1}{2}$ feet long. They are bolted together in pairs, and are so disposed that vertical rods of square iron may fall from the joints of each chain alternately in parallel lines 5 feet apart, to support the road platform.

The road platform is raised, or 'cambered' nine inches in the middle, is formed of two lines of flat iron bars, 4 inches by $\frac{3}{4}$ inch, set on edge, and suspended on each side of the bridge from the vertical rods; carrying cross joists and longitudinal planking 3 inches thick, covered by an upper layer of cross planking $2\frac{1}{2}$ inches thick. The planks were imbedded in a composition of resin boiled in linseed oil mixed with ashes. A cornice or moulding of wood is secured along, and protects the outside edges of the planking, and a trussed hand-rail of pillars and diagonal braces of iron, surmounted by a stout wooden top-rail, runs from end to end of the platform on both sides. The quantity of material employed in this small suspension bridge

is 14¾ tons of ironwork, 36 tons of wood, and 91,388 cubic feet (or 3385 cubic yards) of masonry. The cost of the finished structure is not given.

The details of the work throughout display considerable ingenuity and neatness in the fittings and attachments, and in the precautions taken to allow free movement in all parts of the ironwork without injury to the masonry; the ironwork is all hand-wrought, and the pin or bolt-holes are all accurately bored by hand to exact fit. The ready resource and patient labour that must have been exercised in carrying out such a piece of work in the far interior of the country so far back as the year 1840 or 1841, by the aid only of native workmen and appliances, is sufficient warrant for the inclusion of this suspension bridge in any mention of early bridge structures in India.

Another very early example of an iron road bridge is the singular but pleasing structure built over the Gumti at Lucknow. This bridge consists of three cast-iron ribbed arches, supported on piers and abutments of brick masonry, carrying a roadway 30 feet wide at a height of 35 feet above low water in the river. The centre arch has a span of 90 feet, with a rise of 7 feet, and the two land arches are each 80 feet span, rising 6 feet in the centre, giving a graceful curvature to the outline of the bridge. The piers and abutments are built on wells sunk into the river-bed. The structure crosses the Gumti almost immediately opposite the site of the old Residency of Lucknow, memorable for its gallant and successful defence when besieged during the Mutiny of 1857. The history of the Gumti iron bridge is in some respects curious. The structure is said to have been designed by Rennie, the great engineer, architect, and builder of London Bridge. The ironwork was received in Lucknow in the year 1798, during the reign of Nawab Saadut Ali Khan, King of Oude, only about twenty years after the erection of the first iron bridge in England, and it is supposed that General Martin, the talented and eccentric French officer, then living in Lucknow, suggested the idea of the bridge to the Nawab. It is probable that the unfamiliar character of the work caused the project to be laid aside, for the ironwork remained unused in Lucknow for more than forty years, when it was at last erected, and the present bridge completed in the

years 1841 to 1844, at a cost of about £18,000, without including the sum paid for the ironwork, which is not known.

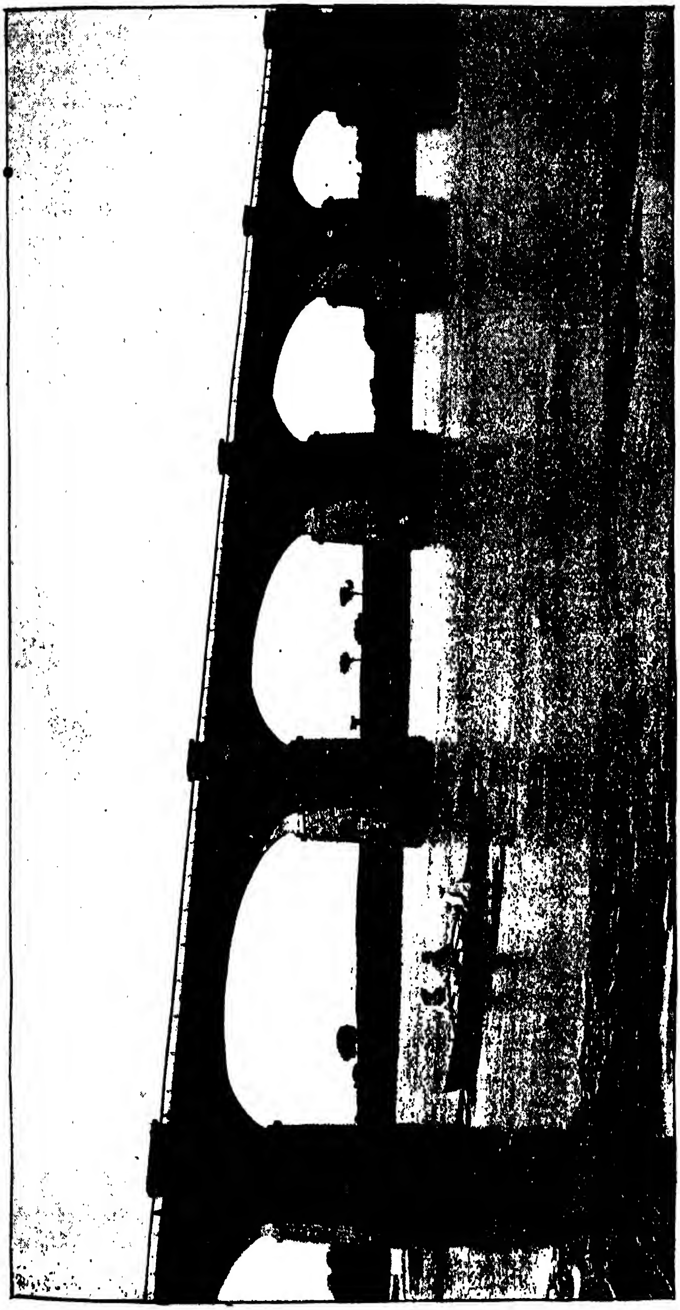
An early masonry road bridge of some interest is that constructed over the Tambrapurni river, in Tinnevelly, in the year 1843, known as the Palamcotta bridge. This is a handsome structure; its architectural elevation having been copied (on a reduced scale) from the Waterloo Bridge over the Thames in London. The bridge consists of eleven elliptical arches, each of 60 feet span and 17 feet rise in the centre, springing from ten piers averaging about 10 feet in height above low water, and the same in width, with two abutments 15 feet thick at springing level. The breadth of the arch-work on the under side is 27 feet, carrying a level road across the river 24 feet wide and 800 feet long. On each face of the bridge two Doric columns stand on the projecting cutwaters of the piers, occupying the space between the arches, and supporting a bold entablature with balconies. An open balustrade on each side extends along the entire length of the work. The piers for the most part were founded on hard rock *kunka*, situated at a small depth below the river-bed, but three consecutive piers were built on rows of small wells, sunk to a depth of 10 or 12 feet only, where a firm bed of clay was met with. Along this portion of the work, up and down stream lines of wells were also sunk to serve as curtain walls, and to retain a pavement or flooring to protect the foundations. The interior of all the wells was built in solid, and the spaces between them were filled in with rubble stone in cement up to low-water level. On this foundation the three footing courses of the piers were laid in stone, with cut-stone face work cramped with iron. Above the footing courses the bridge is constructed of neat brickwork partly stuccoed.

On the Lahore and Peshawur road, a plain substantial bridge of combined stone and brick masonry crosses the Sohan river, a stream draining an area of nearly 600 square miles; the depth of water during high floods being 15 feet, with a mean velocity of current of 9 or 10 feet a second. The discharge of the river in floods is calculated at about 91,000 cubic feet a second, and at the site of the bridge the river is over 1000 feet wide. This example will serve as a typical illustration of the larger class of

road bridges constructed in India, which are to be met with more or less frequently. The Sohan bridge consists of fifteen brick arches each of 63 feet span, carrying a cut-stone cornice, and a level roadway 26 feet in width. The arches are supported on piers and abutments of coursed rubble masonry, 35 feet high from lowest foundation to the springing of the arches. The bridge was built in three sections of five spans each, the abutment piers and end abutments being 12 feet, and the intermediate piers 9 feet in thickness. The foundation footing courses, which rest in firm red clay, are laid at a depth of 17 feet below the river-bed, and are protected by a continuous flooring of stone blocks, and up and down stream curtain walls, carried down to the same level as the foundation masonry of the piers. The clear waterway of the bridge is 945 running feet, the cost of the structure having been about £4300.

Probably the largest of the very numerous ordinary road bridges constructed in India is that over the Kanhan river on the northern line of road from Nagpur to Jubbulpore in the Central Provinces. This bridge—which was constructed between the years 1866 and 1873—adjoins the military station at Kamthi, situated about ten miles north of Nagpur. The Kanhan is a river of considerable magnitude, tributary to the Weingunga. The accompanying illustration, which represents a third of the total length of the road-bridge constructed over it, will convey an idea of the main features of the structure.

The Kanhan bridge, with the exception of the ornamental balustrade or parapet, which is of cast-iron, is constructed throughout of sandstone masonry; the stone for which was obtained from quarries situated along the north bank of the river, within a few miles of the site of the work. The bridge is constructed on a severely plain, but at the same time handsome design, and conveys an idea of solidity combined with lightness and boldness of outline. It is about 1300 feet long over all, and consists of twelve flattened arches of 80 feet span, springing at nearly the highest flood-level of the river, or at a height of 39 feet above the mean summer water-flow, each arch having a rise in the centre of 16 feet only, or one-fifth of the span. The total available waterway of the bridge is 38,400 superficial feet clear of any contraction, and as the maximum



ROAD BRIDGE OVER THE KANHAN RIVER AT KAMTHI.

flood discharge of the point of crossing is calculated at about 458,000 cubic feet per second, a current velocity of 12 feet per second is required to pass the highest floods. The bed of the river consists of pure sand overlying Gneiss rock. The latter is found almost on the surface immediately below the northern bank, but dips gradually and irregularly to about 30 to 32 feet below the lowest water-level on the southern side of the river. The piers and abutments of the bridge are everywhere carried down to the solid rock, which was cut into level benches to receive the lowest foundation courses of masonry.

The construction of the present Kanhan bridge was commenced in the year 1866. Several years before this date, however, an unsuccessful attempt had been made to bridge the river, at an ill-chosen spot, situated about a mile higher up the stream, where the channel was contracted in passing through a gorge, just below the confluence of three large rivers, viz. the Pench, Koilar, and Kanhan, and where, during high floods, the velocity of the current was necessarily extremely rapid. This first proposed bridge was designed to have twelve arches of 59 feet span each, springing at a height only 28 feet above the bed of the river, giving a total water-way of about 17,000 superficial feet. The piers were designed to be founded on wells, sunk into the sandy river bed, where the depth of sand overlying the rock below was insufficient for this particular method of foundation. During the course of a high flood in the year 1864, all the works under construction at this bridge were undermined and destroyed; the piers and foundation wells being completely overturned and carried away.

At this time, and for many subsequent years, the 185 miles of road between Nagpur and Jubbulpore, was perhaps the most important link of communication in India, connecting, as it then did, the terminal points of the open line of railway from Bombay on the one side, with the East Indian Railway system on the other. For many years all passengers and mails, to and from Bombay, Calcutta, and the Upper Provinces, had to pass between the two railway termini at Nagpur and Jubbulpore, by means of this line of communication, until that difficult and expensive portion of the Great Indian Peninsula main line, traversing the Nerbudda valley between Khandwa and Jubbul-

pore, was completed. The removal of the obstruction to traffic caused by the Kanhan river, during the four or five months of the rainy season, was, therefore, a matter of such considerable moment, that after the destruction of the works on the first bridge, it was almost immediately determined to commence the construction of the present one, on a new and much superior site, and with a greatly enlarged waterway. A short description of this fine work, together with some of the more interesting details of its construction, will afford a suitable example of the largest class of road bridges in India.

To obtain a secure foundation for the piers and abutments of the bridge, which would be exposed to the full force of that great depth and velocity of current which we have already indicated, it was obviously necessary to commence building operations on the solid rock, which had been proved by borings to exist at varying depths, from a few feet on the north side, to upwards of 30 feet below the level of the lowest summer flow on the south side of the river. Between this water-level and the very irregular surface of the rock beneath, the space was occupied by pure clean sand. In order to lay bare the surface of the rock at the site of each pier or abutment foundation, it was necessary to excavate and remove this overlying sand, and whilst doing so to exclude the entry of water, which would inevitably wash fresh sand into the excavation. This could only be done by employing what are technically called *cofferdams*. A cofferdam, according to the depth or head of water to be excluded, is formed of a single, or a double row of pointed piles, driven closely together round the site of a foundation, so as to enclose it. When the piles are driven down to the necessary depth and the cofferdam is completed, the water is pumped from the interior area by means of steam-pumps, and the solid material within can then be excavated to any depth desired, within the limit of depth of the cofferdam itself.

In all ordinary cases of the employment of these enclosing dams, whether single or double, the piles are driven into some retentive bed of clay or other material, sufficiently firm to serve as a foundation for the intended structure, and to some distance below the level of the actual commencement of the foundation courses. It is obvious, however, that when the

season, the central supports of the timber work were carried, either directly or through the intervention of dwarf piers, on the rock-bottom of the river, and were protected by a heavy mass of rough stone thrown round them. Several of the bridge centres, during the construction of the arch-work, were exposed to the severe action of floods of nearly maximum volume, with perfect safety and success. The width of the centres on their upper surface was 25 feet, and their height from lowest water-level to the crown of the arches was 55 feet. Including foundations, the maximum height of the centering reached about 75 feet. In the construction of the temporary timber work, including renewals during its use, 37,500 cubic feet of timber, and more than 50 tons of manufactured iron-work in the shape of straps and bolts, were employed; the total weight of wood and iron in each centre being about 300 tons. The temporary centering of the arches cost £17,800, or at the rate of nearly £1500 per span of the bridge.

As soon as the erection of the first timber centres was complete the construction of the archwork commenced. The arches of the Kanhan bridge are 80 feet in clear span, 24 feet wide, and have a rise in the centre of 16 feet. They are of oval outline, composed of seven blended curves; the tangent to the first curve being vertical. From the haunch stones resting on the piers to the keystones in the centre, the archwork is built of radiating stones, each of the full depth of the arching. These stones vary from 6½ to 4¼ feet long, and are of proportionate breadth and thickness. Their weight varies from 2½ to ½ a ton each, and the average number in each arch is about 1000, or 12,000 in the whole bridge. The total weight of a single completed arch is 735 tons, and the calculated pressure at the keystones in the centre is 22,000 lbs. per square foot, or 152 lbs. on every square inch. When the support afforded by the centres was removed, the average sinking or settlement of the whole twelve arches was under 1½ inches, the maximum being under 2½ inches. This exceedingly small settlement was due to the extreme thinness of the mortar joints between the arch voussoirs, and to the perfectly even and level bed to which each arch course was worked before the next was laid on it.

On the successive completion of every arch, the 'striking' of

the centres—that is to say, their removal from contact with the arch masonry, so that the latter might be left self-supporting, was effected in the following manner. The centering was divided into two portions, from about the line of the springing level of the arches. The upper or arch-shaped portion consisted of six vertical ribs, firmly braced together, and covered at the top with 'lagging' or planking to receive the arch-stones. Between this upper portion of the centering and the lower division sixty iron cylinders, disposed in six rows of ten each, were interposed. Each iron cylinder was 15 inches high and 12 inches in diameter, and was filled with fine dry sand. The whole upper division of the timber work, weighing from 90 to 100 tons, was supported on this sand, through the intervention of sixty wooden plugs, each 11 inches in diameter, which entered the cylinders. Near the bottom of the latter two holes about an inch in diameter were bored, and were kept firmly closed by wooden pegs or plugs, but when it was desired to lower the upper portion of the centering and detach it from the archwork, the 120 plugs closing the holes in the sixty iron sand cylinders were simultaneously withdrawn, permitting the dry sand to slowly escape, and the whole mass of timber work forming the upper portion of the centering to descend in a regular and even manner for a vertical distance of one foot, or until well clear of the arch masonry. By this method of lowering the heavy timbering all concussion and jar to the archwork was avoided, and the operation of striking the centres was performed with the most perfect ease and success.

The upper line of the Kanhan bridge is crowned with a massive and boldly projecting cornice of ashlar stone, carrying a cast-iron balustrade or parapet, the width of the level metalled roadway over the bridge being 20 feet. The total quantity of sandstone masonry in the whole structure is 975,640 cubic feet, or 36,135 cubic yards, of which 158,640 cubic feet, or 5876 cubic yards, is composed of archwork. The bridge was opened for public traffic in September 1873, the total cost to the local Government of the Central Provinces, exclusive of the road approaches, amounting to £109,550, or about £84 per foot run of bridge.

A short time after its completion the Kanhan bridge was

temporarily used to carry—in combination with the road traffic—a narrow-gauge railway, which was constructed to connect Nagpur with the rich grain-producing districts of Chattisgarh. On the recent conversion of this line of railway into one of a broad gauge, and its extension to join the East Indian Railway near Calcutta, an independent railway bridge of iron girders was constructed over the Kanhan river, not far from the site of the older work, which then reverted to its original character and use as a road-bridge.

Very little statistical data or information appears to be available in connection with road construction generally in India. In the ten years from 1848 to 1858 it is recorded that some 30,000 miles of roads of various classes were constructed, of which 5000 miles were of the first-class metalled and bridged type. During the following fifteen years road-making—more particularly in the Central Provinces and in the Punjab—was energetically carried on, but the rapid growth of the railway system from this time gradually diminished the importance of new trunk lines, except in the hill regions of the Himalayas and other outlying portions of the country beyond the probable immediate reach of railways. To such places important new roads were, and still are being constructed. Local district and railway-feeder roads—especially in times of scarcity or famine—have, however, continued to be made in all the chief provinces; their construction having in the year 1871 been handed over to local boards or committees, duly provided with the revenues or grants considered necessary for the purpose. A sufficient extension of railway feeder-roads, capable of being kept open during the entire year, still remains, however, a very urgent need in many districts.

No accurate estimate can be formed of the total length, even of the main metalled and bridged roads now existing in India, but it is stated that during the thirty years previous to 1889 the amount expended from general and local funds on ordinary roads and bridges throughout the country does not fall short of RX.1,500,000 [1]—or a million and a half sterling—a year, and all important centres of population in the chief provinces—especially of Upper India—have now long been connected by lines of permanent highway.

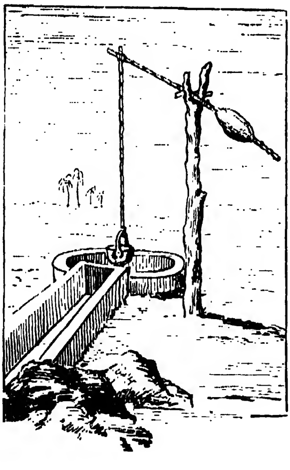
[1] *Indian Administration during the past thirty years.*—Parl. Paper, 1889.

IRRIGATION WORKS IN INDIA

CHAPTER I

NATIVE WORKS

Early introduction of irrigation into India—Rainfall conditions—Bengal—North-West Provinces—Punjab—Scinde—Bombay and Madras—Modes of obtaining water for irrigation—Varieties of canals—Native works—Ancient inundation canals—Native state of Bahawalpur—Uncertain and irregular system of irrigation—Madras irrigation—Storage tanks—Channel irrigation by means of 'anicuts' or weirs—Kaveri Delta irrigation—The 'grand anicut'—Native weirs—Mode of construction—'Bhandaras' in Khandesh—Tanks in Mysore and the Carnatic—Examples of large tanks—Ponairy tank—Viranum tank—Chembrembaukam old and new reservoir—The Cammun tank—Lokain embankment—The Nuggar ancient tank in Mysore—The Kaveri Pauk tank—Description of the Madduk Masur tank.



THE value of artificial irrigation and its employment for increasing the fertility of the soil, was in very ancient times well known and practised in India. Its early introduction is no doubt of Hindu origin, and its greater or less prevalence in any district was, as it still is, mainly dependent on the deficiency or abundance of the rainfall, and the supply of water carried by the water-courses and rivers of the country. In the extreme eastern districts of the Province of Bengal the annual rainfall is so abundant and regular in quantity, that artificial means of irrigation are needless, and failure of the crops is practically unknown. In Behar and Orissa the rainfall is ordinarily large and even excessive, but less certain; disastrous

failure occurring at long intervals, such as occurred in the latter district in the year 1866.

Over a great portion of the Lower Province the high annual rainfall, added to that precipitated on the slopes of the Himalayan range to the north, occasionally floods the rivers with such great volumes of water as to inundate the country and damage the crops by excess of moisture. Artificial irrigation is here more commonly resorted to for the cultivation only of the cold weather crops.

In the higher Provinces to the north-west, however, the rain clouds coming up from the sea, before meeting the northern range of mountains, have first to pass over immense tracts of highly-heated land, and have already discharged a large portion of their contents. Hence arises that almost constant scarcity of water for purposes of cultivation, which renders artificial irrigation in this region of such inestimable importance.

Still farther to the westwards, over the greater part of the Punjab Province, south of Lahore, the amount of annual rainfall rapidly diminishes, many districts being practically rainless. In this region, without the aid of water drawn from the great perennial rivers or from wells, agriculture becomes virtually impossible. Over a large tract of the central districts of India the conditions are much the same as in the North-West Provinces, the average annual rainfall being between 30 and 40 inches, increasing gradually in quantity to the eastwards of Nagpur.

Along the line of the Western Ghats, from the Gulf of Cambay to Cape Comorin, the rain-laden clouds from the south-west principally discharge themselves on the high lands immediately adjoining the coast, giving a fall averaging 100 to 150 inches; but, as a consequence, farther inland, over a long central belt of country extending from Khandesh to the extreme southern point of the peninsula—comprising nearly all the central portions of Bombay, Hyderabad, and Madras—the annual rainfall is scanty and inconstant. In the southern portions especially of this tract, owing to the fall of the country, the water is carried off by the rivers with great rapidity, hence arises that immense development of artificial tank and other irrigation, under both the ancient and modern rulers of the

country, for which the extreme southern part of India is so celebrated.

There are three special methods of obtaining a supply of water for irrigation purposes, viz., by means of wells, storage tanks, and canals derived from the rivers of the country—any or all of which may be combined. Canal methods may be divided into several classes. First, there are simple 'inundation' canals, consisting of water-channels, artificial or semi-artificial, unprovided with any means of regulating and controlling the supply at the head—which lead water away from the rivers, and are filled only when the latter are in flood, being incapable of drawing off water at other times. Secondly, there are canals which may be called 'periodic.' These are derived from rivers having a changeable and uncertain supply. In order to prevent the water running to waste, some kind of temporary or permanent dam is constructed across the river bed, to intercept, store up, and divert the water into the canal, either during the rainy season only, or more constantly, as the supply in the river admits. Lastly, there are those which are called constant or 'perennial' canals. These draw their supply from rivers which at all times of the year run with a sufficient volume to supply the canals, without previous storage, and are supplied with dams or weirs, and necessary works at the head for raising and regulating the supply of water as required.

Wells, artificial storage tanks, and inundation canals have for ages been largely employed by the natives of the country, also to a certain extent 'periodic' canals; but it is only during the period of British rule, with small exception, that the great class of 'perennial' canals have been constructed.

Over the greater part of the Indus basin, the cradle of the first civilised races in Hindustan, and especially in those almost rainless portions, where cultivation, without the fertilising influence of water would have been impossible, evidences of ancient 'inundation canals' for irrigation are to be met with in great quantity. These artificial cuts were sometimes of large dimensions, in some cases they were no doubt originally old abandoned river-channels kept open by continual clearance. As their name implies, they could only be of service during the period when the rivers were in flood.

In the early part of the year, under the influence of the growing heat of the sun the water stored up in the form of snow on the Himalayan mountains is gradually released. Increasing volumes descend the Indus and other snow-fed streams, and the canals are filled; the water reaching its maximum body during the fierce temperature of the summer months, when for the purposes of man it is most required; but during the winter months of the year, the level of the water in the river remains at too low a level to enter the elevated channels. These inundation canals, together with wells, were the only means of irrigation available in very ancient times in the Punjab and Scinde.

A very large number of early inundation canals are to be met with in the almost rainless regions of the Indus basin, especially in the great alluvial plain below the junction of the five Punjab rivers. In size they vary from 10 to 300 feet in width, from 3 to 10 feet in depth, and are of all lengths up to sixty or seventy miles. As already stated there are no head works to control the supply of water, and irrigation from them is carried on by means of branch cuts leading from the main canal, which feed the minor distributing channels. The excavations are carried at such an angle from the parent stream as to gain as great a fall as the nature of the country admits. Owing to the constant encroachment or recession on either hand of the Indus, these canals are most difficult to keep open from season to season. The Indus brings down an enormous quantity of material held in suspension in its waters, which being deposited along its course causes a gradual raising of its bed. The banks also are constantly being eroded, thus there is a continued action tending to fill up the channels derived from it, necessitating heavy periodical labour to keep them clear. The greatest deposit takes place in the portion nearest to the river, where it often reaches 5, to even 10 feet in depth; and in order to preserve the original level, stone posts are set up to mark the limits of clearance required.

Owing to the elevated position of the bed of the Indus, the highest land is at the river banks, and the inundation canals are cut through this relatively high margin in order to carry water to the lower levels removed from the stream. An

interesting example of these ancient canals is that called the 'Bigari,' on the right bank of the Indus, below Sukkar. 'In 1844 it was described by Lieutenant Maclagan as having a total length of forty-eight miles, with a fall of 38 feet. The head was on a side channel at a distance of nearly seven miles from the Indus. For the first twenty-three miles it passed through a country covered with jungle, but presenting frequent traces of former cultivation. It was then becoming yearly smaller from the defective system of clearing. At the head it was 24 feet wide, with a depth of 9 feet. This canal in 1854 was enlarged, and its capacity nearly doubled, by the British Government. One of its main branches or offshoots was also cleared, numerous villages sprang up along its course, and the town of Jacobabad was founded in the midst of a barren, treeless waste, the tail being extended to the Kelat boundary, near Khyra Garhi.'[1]

Another large and ancient inundation canal, originally following a natural branch of the Indus, is that known as the 'Fuleli'—from Hyderabad, in Scinde, to a point on the Indus sixteen miles below. The junction of the natural channel at the latter point was closed by a dam in the time of the Amirs, and the water was utilised to feed the Gaja Guni and other canals to the southwards. A large number of the very numerous ancient inundation canals and their branches in this part of the Indus valley have during comparatively recent years been improved and rendered exceedingly valuable for the wants of this arid region.

In the higher portions of the Indus valley above Multan, and in the valley of the Sutlej, inundation canals were formerly numerous, and the rich country of Muzaffargarh between the Chenab and the Indus, was one sheet of cultivation. In a former age such canals were conducted from all the five rivers of the Punjab, and traces of them are perceptible, with ruins of cities and villages on their banks. In the central parts of the 'Bari Doab,' above the Multan district, the face of the country is covered with traces of former life and prosperity, due to inundation canals derived from the old 'Beas, which, before it

[1] *Statement exhibiting the Moral and Material Progress and condition of India during the year* 1872-73.—Parliamentary Paper.

was diverted into the Sutlej in 1790, had an independent course to the Chenab.'

The chief canals of the upper Sutlej system are the Kanwah and the Sohag. The Sohag canal leaves the Sutlej a little below the mouth of the Kanwah, and irrigates the country between that canal and the river. It is seventy-three miles long, and has been much improved under British rule, the channel having been straightened, and masonry outlets constructed. A continuation of the Sohag is connected with the old Beas by a cross channel called 'Nawabbin,' a name derived from the Nawab of Multan in the last century, who carried the water into the Beas, and thence into the Multan district, for the purpose of providing a navigable passage for his wife, who was travelling down country in a boat.[1] The Afghan rulers left by Aurungzib were to a great extent, the authors of this system of irrigation.

In the native state of Bahawalpar a great number of inundation canals formerly existed, fed from numerous branches of the Ghaggar—the ancient 'Saraswati'—which formerly flowed through the country to the Indus. After the bed of the Ghaggar dried up, and the desert sands had encroached over large districts which had once been fertile and populous, many of the old branches of the Ghaggar continued for a long time to be partially supplied with water by cuts made from the Sutlej to their nearest points, but gradually, year by year, more and more land fell out of cultivation, until nearly the whole of the upper north-east portion of the State became practically a desert. Since the year 1867, under the fostering care and energy of the English political agents in power during the minority of the Nawab of Bahawalpur, a large amount of prosperity has been restored to these regions. Numerous inundation canals of considerable size and length have been constructed, together with some few perennial canals, drawing off the Sutlej water from below the winter level. Many of the older water lines have also been reopened, and the blessings of extended irrigation have once more been diffused over the land.

'The important system of inundation canals from the Punjab

[1] *Statement*, etc., *ut supra.*

rivers, upon which the very existence of the inhabitants of a vast area in the rainless region depends, was administered in former times by the people themselves. The whole of this class of canals within British territory has now long been placed under the regular management of the Irrigation Department. Until a comparatively recent period there was no direct canal revenue from this class of canals, the returns appearing only in land revenue.'[1]

It is obvious that inundation canals, under any circumstances, afford a very irregular and uncertain system of irrigation, being entirely dependent on the fixed volume, regular periodicity, and duration of the river floods. To convert this system of canals into one of a certain and permanent character, whether in Scinde or in the Punjab, presents no difficulty beyond that of expense, but this consideration has exceptional force owing to the comparatively sparse population and poverty of the districts where the system is chiefly met with.

In the southern districts of the Madras Presidency, where the rainfall is small and exceedingly precarious, and river supplies are more difficult to obtain, an enormous number of artificial tanks or reservoirs for the storage of water, some of great antiquity, are to be found. These tanks, often of prodigious size, and displaying in their construction a very high degree of engineering skill, were, and still are, so contrived as to collect during the rainy season, and store up large bodies of water for use during the season of drought. The storage of water in reservoirs for irrigation purposes, although reaching an unusual development in Madras, was in early times as it is at present, common over the greater part of India. In the neighbourhood of almost every large town, reservoirs or tanks for bathing, washing, and drinking purposes, are very numerous. These tanks are usually fed by the surface drainage of the immediate ground. Some of them are of very considerable size, and are enclosed by massive masonry walls, having flights of steps at intervals for the convenience of bathers. Large trees, affording a grateful shade, overhang the banks, and picturesque temples or shrines cast their reflections in the water. Many of these tanks are of great beauty, as that of Saugor in the Central

[1] Parliamentary Paper, *vide* note, page 8.

Provinces, or the Holy tank in the centre of the large commercial town of Amritsar, in the Punjab. The latter, with its golden temple in the centre, connected with the shore by a marble footway, and the quiet seclusion of its surrounding marginal platform, forms one of the most striking and beauteous objects in India.[1]

The main feature of the ancient irrigation system in the Madras Presidency was, to a great extent, as it still is, the employment of large or small tanks for the storage of water, but channel irrigation was at the same time extensively practised. The smaller streams of Southern India are frequently mere torrents, carrying off the water with great rapidity, so that they become dry after a few hours. In order to utilise the water for irrigation purposes, it was intercepted by *anicuts* or weirs, built across the streams. It is only the larger and more important rivers that can supply means of irrigation on a large scale directly from their channels, and probably all these rivers were to some extent laid under contribution in former times. The most interesting example is perhaps the Kaveri Delta irrigation in the district of Tanjore, which, designed and constructed by native engineers, contained the germ of the great Delta schemes subsequently carried out by the British Government. Near the head of the Kaveri Delta, 'the ancient native work, called the "grand *anicut*," was a solid mass of rough stone, 1080 feet long and 40 feet broad, stretching across the bed of the Kaveri in a serpentine form at the lower extremity of Seringham island. It was built upwards of 1600 years ago.'[2] The improvement of the Kaveri system of irrigation was the earliest irrigation work undertaken by the English Government in this part of India.

'Tinnevelly, the southernmost district of Madras, is watered by the Tambrapurni river by means of *anicuts* placed at intervals across the stream, whence channels are led, either directly for irrigation, or to supply tanks—the number of which in this district is exceedingly large. The *anicuts* are earth-embankments with masonry sluices: they are very

[1] *Vide* 'Public Works in the Bengal Presidency,' vol. xviii. *Proc. Inst. Civil Engineers.*

[2] Parliamentary Paper, *vide* note, p. 8.

ancient native works.'[1] In the middle reaches of many of the larger rivers there are to be found ancient *anicuts* or weirs of stone, generally admirably situated, but of rude and imperfect construction: many are ruined, and others require extensive annual repairs to keep them serviceable. Advantage was usually taken of a reef of rocks running across the river, the low places being filled in with rubble, or random stone, faced on both sides with large blocks laid dry, and occasionally fastened together with cramps. There is in most cases much leakage through the body of these native weirs, but it can hardly be due to this circumstance, that although they are not provided with sluices for creating a scour, the river-beds on the upper side of them do not appear, except in a few cases, to have been materially raised.[2]

The sites of many of the old *anicuts* thrown across the rivers in this part of the country have often been so judiciously chosen by the native engineers, that very little expense has been incurred in constructing them. One across the Tumbuddra river in the Belari district, at a point where it is divided into two streams by an island, is an interesting instance. Between the island and the river banks there are a number of smaller islands, or clusters of granite rock. These have all been utilised in constructing the long *anicut*, which itself consists simply of boulders and blocks of granite thrown promiscuously together to fill up the spaces between the natural portions. The irrigation channel taken off above this weir is 25 feet wide and 3 feet deep, with a fall of 1 foot per mile.[3] Nine such *anicuts* on the Tumbuddra were constructed by the Rajahs of Bijayaangar in 1521 and subsequent years, and irrigation channels of a total length of eighty-nine miles were led into the valley.

In construction the native weirs are of a simple character, but nevertheless very effective for their purpose. The up-stream side is often formed by a slightly 'battered,' that is, inclined wall, carefully built of large-sized stones, with extra long ones, or 'headers,' inserted at frequent intervals. The stones of the top row next the water are sometimes notched together, or

[1] Parliamentary Paper, *vide* note, p. 8.

[2] Vide *Minutes of Proceedings, Institution of Civil Engineers*, vol. xxxiii. session 1871-72.

[3] *Ibid.* vol. xxvii. session 1867-68.

bound with iron cramps. A long apron, or slope, formed of rough stones thrown promiscuously, extends on the down-stream side, and along the foot of the slope two or three rows of very large and heavy stones are carefully laid, to prevent the escape of the rough stone forming the apron. In some cases the upper surface of the latter is set with stones regularly laid by hand, so as to give it a smooth surface. The *anicuts* are invariably founded on a rocky bottom; the construction of permanent weirs across sandy-bedded rivers having probably been beyond the skill of the old native artificers.

In the Bombay Presidency the British Government have inherited from ancient times a series of weirs on almost every perennial stream in Western Khandesh. These old weirs, or *bhandaras*, are found from near the source of the rivers as far down as suitable land for irrigation exists—or as far as it is possible to construct them at a reasonable cost. Originally the weirs, from the existence of curious square holes cut in the rock near the sites of many of the existing works, appear to have been wooden structures, or temporary dams of earth strengthened by wooden posts. Wood, however, became scarce, and now the dams are either of solid masonry or occasionally of earth and sand. The number of *bhandaras* in working order in Khandesh and Nasik is now about 200, but there are also many ruined and abandoned ones.

The channels which lead the water off from the *bhandaras* to the irrigated fields, usually skirt along the river bank, with little or no protection against the river floods, until they reach the higher land. The alignment of the channels show little regard for cross-drainage or levels. As a rule physical obstacles are avoided by following a contour line; small streams are crossed on a level, while the bed-falls of the channels are often very insufficient. The ground at the commencement is often very broken, and originally the channels ran for long distances up the hollows, or intercepted streams, crossing the latter on a small bank which would be carried away by every freshet, then down again to get round the hillocks, in and out in a most tortuous course, at times clinging to the precipitous cliffs of the river until more favourable ground was reached; and in some places it is extraordinary to note with what patience very

considerable difficulties have been overcome. The original channels have in course of time been improved by the construction of aqueducts and weirs at the crossings of the small streams, protecting walls have been built and diversions cut to straighten the alignment. The total area irrigated by these old works is nearly 24,000 acres.[1]

The amount of irrigation formerly and still carried on over large districts in Southern India by means of artificial tank storage is extraordinary. 'Mysore and the Carnatic are covered with thousands of tanks. In the fourteen districts of Madras there are said to be some 43,000, all of native origin, with 30,000 miles of embankments and 300,000 separate masonry works. The tanks are formed in various ways, according to the accidents of the ground. Embankments are thrown across the gorges of valleys, high enough to retain a volume of water proportioned to the irrigable acres situated below. Descending terraces of land are occupied by a succession of reservoirs, the higher feeding the lower from its surplus supply. Long slopes have portions embanked on 3 sides, and the included space forms a storage area for such volume of water as local wants call for.'[2]

It is not known at what period many of the more important of these works were constructed, although the names given to them occasionally afford a clew. Some of the larger tanks are of very great antiquity, and others have undoubtedly existed for centuries. Many are also of enormous size. In a report made in 1853 by Colonel Baird Smith, of the Bengal Engineers, it is stated that the 'Ponairy Tank' in Trichinopoli had an embankment 30 miles in length, and a probable area of 60 to 80 square miles. A reservoir—occurring in the neighbouring island of Ceylon—is mentioned by Sir H. Wood in a paper presented to the Royal Asiatic Society, having an embankment 11 miles in length; and another in which the water of a valley is retained over an area of 15 square miles in the rainy season, and not less than three in the driest period.

The Viranum Tank, still in operation after a fabulous duration, has embankments 12 miles in length, about 20 feet high, and

[1] Bombay Irrigation Revenue Report, 1890-91.

[2] Parliamentary Paper, *vide* note, p. 8.

an area of 25 square miles, storing about 100 million cubic yards of water. It is supplied by a canal taken from the river Kalerun. The great Chembrambaukam tank, 14 miles from Madras, has an embankment more than three miles long. Before its enlargement by the British Government in 1867, at a cost of over £40,000, it held from 56 to 78 millions of cubic yards of water, and had an area of 4648 acres, or 7¼ square miles. Its present capacity is 103 millions of cubic yards, with an area of 5729 acres, or nearly nine square miles. It irrigates from 9 to 10,000 acres of chiefly rice cultivation, and its safety is secured by six overflows or waste weirs, having a total length of 676 feet.

In the district of Guntoor, the Cummum tank embankment closes a gorge which is little more than 300 feet long; whilst the area of the reservoir itself measures about eight square miles. The embankment is more than 100 feet high, made entirely of earth, with slopes of 2 to 1, the inner slope being carefully laid over with large stones. On the river Lokain, an embankment no less than 117 feet high closes a gorge which is but a little over 200 feet in length, the base of the earthen embankment measures 400 feet. The Nuggar, ancient tank in Mysore, has an embankment 1000 feet long, about 85 feet high, and 600 feet broad at its base. The margin of the tank measures 40 miles round. The 'Kaveri Pauk Tank' in North Arcot is also of very great size and antiquity. It is fed from the Pallair river: has embankments nearly four miles long, revetted along its entire length with stone, and irrigates about 7700 acres.

The following interesting description of one of these large ancient native tanks, which will afford a clear idea of their construction, is taken from a paper read before the Institution of Civil Engineers in 1872, by Mr. G. Gordon, M.I.C.E.:—

'A good specimen of the tanks is one which the author was deputed to examine a few years ago, with a view to its restoration. A short description of it will afford an idea both of the construction of ancient works and the untrustworthy nature of the data which old works seem to afford for the construction of new works.' The tank is named the Madduk Masur Tank. 'This great work is believed to have been constructed under

the Annagoondy dynasty, about four centuries ago. It was formed by an embankment resting on the sides of a narrow gorge through which the river Choady passed, supplemented by two *bunds* or dams, on saddles in the range of hills; that on the east being 1350 yards, and that on the west 670 yards from the main *bund*. The length of the main *bund* is 550 yards on the top. The inside slope of $2\frac{1}{2}$ to 1—in some parts 3 to 1—was revetted with large stone up to a cubic yard in bulk. It is from 945 to 1100 feet broad at the base, and is now from 91 to 108 feet high. There was a sluice under the dam at the east end, about the level of the ground.

'The dam is composed of a strong red earth, with a considerable admixture of gravel taken from the sides of the hills on which it rests. The east supplemental *bund* has its base 74 feet above the sluice in the main *bund*, and had also a sluice under it at the ground-level. The west supplemental *bund*—the breaching of which destroyed the tank, seems to have been of similar construction to the others, and its base was perhaps 50 or 60 feet above the bed of the tank. There is no trace of any waste weir, and it is probable that the want of this was the cause of the ruin of the tank. On the main *bund* there are what appear to be traces of the water having topped it, and having cut into the rear slope in two deep gullies. The west *bund* had probably a sluice in it which weakened it, as cut stones were found in the river some way down.

'After this *bund* was breached, the water cut into the ground on which it stood to the depth of 100 feet, and would have completely emptied the tank but for a reef of rock some distance from the dam on the inner side, which now causes a waterfall 25 to 30 feet in height, and retains about 10 feet of water in the tank. On this reef a weir has been built.

'From the heights of the dams and the levels of the sluices, it is probable that the depth of the tank was 90 to 95 feet; and at that level its area would have been 40 square miles, and its contents about 1400 million cubic yards of water. The drainage basin is about 500 square miles, and three-fourths of it lies within the jungly district containing the spurs of the Western Ghats. It is found from observation of the discharge of the river that a good average monsoon supply would not

exceed 668 million cubic yards, or 16 inches running off. It is not probable that the average annual rainfall, so near the Western Ghats, has diminished so much, although it may to some extent, from land having been cleared of jungle. The difference between the present supply and what it must be supposed to have been, when the tank filled and was breached (even supposing that to have occurred in an exceptional year), is probably owing in part to the construction of small tanks on some of the feeders. The tank as proposed to be restored would have contained 644 million cubic yards. As regards capacity, this is the largest reservoir in Southern India of which the author can find any record.'

CHAPTER II

Native works continued—Details of Madras tanks—Chain system of storage reservoirs—Construction of native embankments—Absence or insufficient size of waste-weirs — Description of native *calingulas* or waste-weirs—Manner of drawing water from the reservoirs—Little skill displayed—Function of the larger tanks—Remains of old reservoirs—Diminution of average rainfall—River feeders—Subsequent regulation of river feeders and waste-weirs by English engineers—Ancient canals in Upper India—Feroze Shah's canal from the Jumna—Decree by the Emperor Akbar ordering restoration—Construction of Delhi branch by Ali Murdan Khan—Canal on left bank of the Jumna—Present Eastern and Western Jumna canals constructed on general lines of these old works—The 'Husli' canal in the Bari Doab—Canal from the Sutlej to Sirhind—Remains of old canal near Meerut—Traces of embanked canals in the valley of Peshawur—Conclusion of native irrigation-works.

The general principles of construction adopted by the early tank engineers of the Madras Presidency may be gathered from the many thousands of examples left by them. The reservoirs themselves are of all sizes, and may be divided into several classes. In some cases the opportunity is taken—as in the cases already quoted—to close by a dam, or embankment, of considerable height, some narrow gorge, where a river leaves a range of hills, and so convert the valley above into a deep artificial lake. Many of these kinds of tanks have been breached either from neglect, the insufficient or entire absence of any provision for escape of surplus water in years of maximum rainfall, or in consequence of the water finding its way through the embankments, generally along the outside of the discharge outlets, which are invariably carried through the banks. In other cases, long and comparatively low embankments are carried for miles over one or more streams in the flat country, thus forming above them shallow tanks, often of very great superficial area. Others again are of a smaller kind, formed against the natural slope of the country by means of embank-

ments thrown up on three sides. Tanks of the last two kinds are so numerous in some districts, particularly in Mysore, as to give the idea that as much land is occupied by them as is left to be irrigated, and probably the reality is not very far from this.

In Mysore, as well as in many parts of the Madras Presidency, an ingenious chain system of storage reservoirs, of entirely native origin, has been developed, involving much skilful laying-out and contrivance. This system is one admirably adapted for the special conditions of the localities where it is found, viz., an exceedingly scanty and precarious rainfall, and the consequent necessity of securing and saving every particle of it.

A chain system of reservoirs is laid out as follows. A hill torrent having a sufficiently lengthy course is chosen, especially one having several lateral feeders. Beginning almost at the source, both of the main stream and of the several feeders, a series of embankments at lower and lower levels, is thrown up across the valley, each embankment being provided with an overflow or waste-weir. As soon as the highest reservoir is full, the overflow passes by the weir-channel into the next reservoir below, and this being filled, the overflow again passes into the third reservoir, and so on through the whole series, often extending over many miles of country. It is obvious that this system requires a very careful adjustment of the size of the waste-weirs, so that they may be able to carry off the largest excess of water that may enter the reservoirs in years of maximum rainfall, as otherwise the whole series of embankments might be successively overtopped and breached. Although very considerable adaptive skill has been shown by native engineers in the construction of this class of storage reservoirs, there have also been many failures, owing to miscalculation in the size assigned to the several overflow-weirs, and many of the systems still in operation have been from time to time remodelled by English engineers.

The embankments of Madras reservoirs are usually constructed entirely of earth, dug from the bed of the intended work, of large and often excessive dimensions. No clay wall in the centre, or what is technically called a 'puddle-wall,' is

employed. The earth is thrown up in thin layers from baskets, the crowd of workpeople, men, women, and children, walking over each layer, both in going with their loads and in returning. By this means a very solid and well compacted embankment is formed. Generally speaking, except in the comparatively few larger examples, the height of the embankments of the Madras tanks does not exceed 15 to 20 feet. Most of them have an inner slope of one or two to one, coated with a stone-facing set by hand, 18 inches or 2 feet in thickness, where stone is abundant. In the absence of stone the inner slope is turfed only, or protected by an arrangement of reeds formed into steps, the object in each case being to prevent the earth of the embankment being injured by the wash of the waves in high winds.

In some cases there is on the side next to the reservoir a massive masonry wall, either quite vertical or slightly inclined. These walls are built of square-shaped dressed stone on the face, closely jointed and backed with rougher masonry or coarse concrete. At intervals, bastions or projections occur, serving to strengthen the walls and to break up its otherwise monotonous outline. Frequently between the bastions broad flights of steps of cut stone lead down to the water, enabling the natives of the place to bathe or wash their clothes. One of the most fruitful sources of failure in the old native tanks is the entire absence, or insufficient size, of the waste-weirs, or *calingulas* (a Tamil word meaning in this connection 'waste-weirs'). In order to prevent danger to the embankment during excessive floods, storage tanks or reservoirs are, or should, always be provided with a waste-weir, or weirs, of sufficient width to allow the escape of all surplus water after the tank has filled. Such weirs are generally of masonry, built in the land near one end of the embankment. It is made so much lower than the land itself, and the top of the embankment, that any superabundant water will discharge itself over it.

In the old native practice, all the skill displayed in careful selection of site, and ingenuity in the construction of the work, was very often rendered of no avail, owing to want of attention to or want of sufficient knowledge of these important adjuncts, and there are numerous examples of fine tanks breached and made useless from no other apparent cause than the want of

sufficient length of outlet for surplus waters. These *calingulas* often consist of a rough wall of masonry at one end of the embankment, returned against the pitching or casing of stone on the face of the slope. At right angles to this wall another is built to a height somewhat below the level of highest water which it is proposed to store in the reservoir, and is carried level until it meets the rising ground. On the outside a rough stone 'apron' or slope is thrown. Along the top of the *calingula* wall upright stones are erected, generally about 3 or 4 feet apart, and 3 or 4 feet high. When the rainfall is moderate, or towards the end of the rainy season, the spaces between the stone posts are filled in with earth, straw, and rubbish, or a close wall of turf is built up in front of them so as to retain more water in the tank. When extra heavy rain occurs this obstruction is removed, or the rising water washes it away and so escapes. In some cases the surplus water is passed through orifices left at a low level in the waste-weir wall itself, which orifices can be opened or closed by planks, or rough shutters.

Water is invariably drawn from the tanks through long culverts of brick or stone passing through the embankments. These culverts are sometimes arched, but are more generally covered with flat slabs of stone. They are usually placed about level with the bottom of the tank. The inner end, or head, of the culvert projects somewhat beyond the toe of the slope, and is closed at the extremity, but through the upper side a series of holes, seldom so much as 6 inches in diameter, are cut. Conical plugs of wood are made to fit into these holes, which can be inserted or withdrawn by means of long bamboo handles —often, as may be imagined, an exceedingly troublesome operation. In some cases long upright stones are erected a few feet apart, having cross stones at intervals, with holes of proper diameter cut in them and placed so as to come vertically over the sluice orifices. Through these holes the long bamboo handles are passed, serving to guide them whilst inserting or removing the plugs fixed at their lower ends. In the larger tanks, closed cisterns having projecting steps are often built at the inner end of the culvert passages, having plug-holes at different levels, and various arrangements for reducing the accumulation of mud at

the entrance to the passages. At the outer extremity of the culvert the water is generally discharged into a masonry cistern with raised sides, the walls of which are pierced with holes at different levels through which the water passes to branch channels, and is carried to the fields at various elevations.

From want of accurate knowledge, the area of the discharge orifices is frequently either much too small or too large for the requirements of the irrigation, and but little skill is shown in adapting the size of the openings to the head of water and area of the lands to be cultivated. The larger class of storage-tanks irrigate directly only a limited area of land; their work is to store up a large body of flood-water which would otherwise run to waste, and let it down the river channel below the embankment as required. From the river, over long distances, the water is drawn off by irrigation canals leading to secondary distributing channels, or into other storage-tanks. The smaller class of tanks usually irrigate a given area directly, beginning close under the tank itself. In some cases, as already mentioned, the water is intercepted by a succession of tanks at lower and lower levels, each of which catches the surplus drainage from the fields above it, so that little is ultimately lost.

Besides the enormous number of tanks of all kinds actually in use, the southern country is covered with the remains of old reservoirs, which from one cause or another have been abandoned. In some cases the embankments are intact, but no water is allowed to collect, the original bottom of the old tank having been so fertilised by the silt deposited that it has become more profitable to utilise the area for cultivation, than to employ the reduced volume of water that would now be impounded to irrigate the lands below. There appears to be little doubt that the average rainfall in many districts is at present less than it was in former times, so that in some cases the old tanks would never fill, or the supply would be so reduced as to prevent any large area being irrigated. Along the foot of the Eastern Ghâts numerous instances are met with where both the beds of the former tanks, and the formerly irrigated land below them, have both reverted to jungle.[1]

[1] Vide *Minutes of Proceedings, Inst. of Civil Engineers*, vol. xxxiii. session 1872-73.

In the old native practice large tanks, in addition to the rainfall on their own catchments, were fed wherever practicable by a channel cut from some neighbouring river. The channels were seldom provided with any permanent arrangements at the head for controlling the entry of water; consequently, if some extraordinary fall of rain occurred, either the tanks filled very rapidly, or if they happened to be already full, the waste-weirs were quite incapable of carrying off the sudden and violent influx of water, and so the reservoir embankments would be topped and breached. One of the chief works first carried out by English engineers in Madras was the regulation of the volume of water allowed to enter the tanks through river-feeders, by placing suitable controlling works at their heads, and carrying out the necessary alterations in the dimensions of the waste-weirs, so as to enable them to perform the heaviest duty likely to be imposed upon them. During the last thirty years considerable improvements and enlargements of many of the ancient tanks in the southern portion of India have been effected under the British Government.

Under the rule of the Mohammedan sultans and emperors, especially in the Delhi districts, attention was from time to time directed to the construction of canals, either for irrigation or for the purpose of supplying the wants of large cities and the fountains and baths of the imperial palaces. Elphinstone remarks that the reign of the Sultan Feroze Shah was 'distinguished by the enlightened spirit of his regulations, and the utility and extent of his public works.' Those that still remain afford evidence of the magnitude of some of his undertakings. The most considerable of his irrigation works was a canal that was opened about the middle of the fourteenth century B.C. 'Between the years 1351 and 1388, Emperor Feroze Shah (Tughlak) drew a canal from the Jumna to water his favourite hunting-ground at Hissar, but there are no signs of works of irrigation along the line of his canal, which fell into disuse at his death. The present Hansi branch of the western Jumna canal follows the line of Feroze Shah's engineer, and the pastoral villages at Hissar are entirely dependent on it for the means of watering their cattle. At Hissar a travelled courtier of Feroze Shah erected a building to give his master an idea of a ship

(*Juhaz*). It is now (or was) used as a store-house for the canal, for which purpose its ample "hold" renders it very suitable.' 'For one hundred years no water had flowed to Hissar, when in 1568 the Emperor Akbar issued a decree ordering the canal of Feroze to be restored.'[1]

In the *Journal of the Asiatic Society* for March 1846, No. clxxi., Lieutenant Yule published the 'Canal Act' of the Emperor Akbar, with some notes and remarks on the history of the western Jumna canals. A copy of the *Sanad* of Akbar Shah Badshah, dated Shamal, A.H. 978 (A.D. 1568), is there given, and it is believed to be authentic. After mentioning the earlier work of Feroze Shah in 1351, Akbar says, 'Now that I have given the district (*sarkar*) of Hissar to the great, the fortunate, the obedient, the pearl of the sea of my kingdom, the star of my government, the praised of the inhabitants of the sea and land, the apple of my kingdom's eye, my son Sultan Mahomed Selim Bahadur (may God grant him long life and greatness), my wisdom wishes that the hopes, like the fields of those thirsty people, may, by the showers of liberality and kindness, be made green and flourishing, and that the canal may in my time be renewed, and that by conducting other waters into it, it may endure for ages. For God has said, from water all things were made. I consequently ordain that this jungle, in which subsistence is obtained with thirst, may be converted into a place of comfort free from all evil.'

The *Sanad* records how Akbar ordered the canal to be 'excavated deeper and wider than formerly,' and that 'on both sides of the canal down to Hissar trees of every description, both for shade and blossom, be planted, so as to make it like the canal under the tree in Paradise,' and adds, 'every *purganah* will be satisfied with the number of cuts made by Mirab (the superintendent of the canal), and take no more. . . . He has power to punish as he sees fit every one who takes water out of season.'

About the year 1626 Ali Murdan Khan—a noble of the court of Shah Jehan, acting as his engineer—constructed a branch from this older line of canal to Delhi, first by way of Gohana, and afterwards, on that failing, by the present channel

[1] Parliamentary Paper, *vide* note, p. 8.

passing near Paniput and Soneput. The low ground near the city of Delhi, through which the surplus water of the Nuzuffgur swamp escapes to the Jumna, was crossed by a massive aqueduct of masonry. On arrival at the foot of the rocky hills which skirt two sides of the city the canal flanks them for a short distance, and then passes through them by a bold rock excavation sixty feet deep at the crest, a work that must have entailed immense labour. It then enters the city near the Cabul Gate. An outlet from the right bank within the city supplies a small masonry channel which flows through the centre of the 'Chandni Chowk'—or silver street—partly open and partly covered in. The main canal passes through several streets and arrives at the Negumbod aqueduct, throwing off many minor streams, and carrying a plentiful supply of water to the palace baths and gardens. Thence the surplus water, after working some flour-mills, passes into the Jumna. The Negumbod aqueduct is a fine mass of masonry, carrying the canal above the level of the house-tops.[1] For 150 years this canal continued to be efficient, but in 1753 the Delhi branch ceased to flow. Ali Murdan Khan also constructed a canal on the left bank of the Jumna. It passed for part of its course exactly on the ridge between the rivers Jumna and Hindun, and thus afforded facilities for irrigation both to the eastwards and to the westwards of its course. The bed of this canal having been formed on the natural slope of the country its fall was excessive, amounting to 372 feet in a distance of 130 miles. This, together with the difficulty of maintaining a passage across the mountain torrents near the head, caused it to be abandoned soon after its construction in 1628. Both the present eastern and western Jumna canals have been constructed along the general lines of these old native works.

Under the Emperor Shah Jehan a small permanent canal was also constructed in 1633, in the Bari Doab. 'It was called the Husli canal, and was designed not for irrigation, but to supply fountains at the royal gardens of Lahore. When the Sikhs acquired the sovereignty they led a branch to Amritsar, to supply the sacred tank at that town. The canal followed

---

[1] *Vide* 'Public Works in the Bengal Presidency,' vol. xvii. *Proceedings Inst. of Civil Engineers.*

the natural line of drainage by a tortuous course of 110 miles, and passed through low ground, which least required irrigation.[1]

During the first surveys made over the districts lying between the Jumna and Sutlej rivers—now watered by the Sirhind canals—Captain (afterwards General Sir W. E.) Baker mentions an old native canal supposed to have been excavated by the Souba of Sirhind early in the century. This canal was drawn from the Sutlej a few miles above the town of Rupar, and was led from thence into the lower ground near the ancient city of Sirhind after a course of forty-one miles. Shortly after its construction it appears to have been abandoned, having probably been rendered useless by a change in the course of the river at its head, and no subsequent attempt seems to have been made to remodel it.

Speaking of the districts now watered by the Ganges canal, Sir Proby Cautley[2] makes mention of an old canal constructed by one Mahomed Aboo Khan, belonging to a period anterior to that of British rule in the country. This canal, the remains of which still exist in the neighbourhood of Meerut, 'consisted of a cut made from the West Kali Nadi, near the village of Rampoor, to the head of a small tributary to the East Kali Nadi, called the Khodara Nulla, which rises near the village of Deorala. The length of this cut did not exceed twelve and a half miles, and its dimensions, judging from the existing hollow, could not have exceeded fifteen feet in width. The water, after reaching Deorala, must have passed down the Khodara Nulla to the town of Meerut, in the neighbourhood of which are many groves and gardens, and it is supposed that it was for the purpose of supplying water to these that the canal was originally projected. . . . The canal was merely excavated to a few feet in depth, and the water was supplied from a lake formed by throwing an embankment across the bed of the West Kali Nadi. The flooding of the valley by this retention must have done extraordinary damage to the properties within its limits; the amount of money and labour expended on an embankment of proportions sufficient to gain the engineers'

[1] Parliamentary Paper, *vide* note, p. 8.

[2] *The Ganges Canal*, Sir Proby Cautley.

object, must have been very great; and the necessity for an annual reconstruction of a work which was inevitably destroyed during the rain-floods, and the certainty that water could only have reached the mouth of the canal during the dry months of the year, are facts which reasonably lead us to conclude that no great benefit was ever derived by the cultivators on the high lands in its vicinity.'

In the valley of Peshawur traces and remains of an embanked canal drawn from the Swat River, of a probably early date, have been found, but whether the channel was ever used for irrigation there is no record. The hill-torrents may possibly have carried away its principal features, and no doubt this has often been the case with many old native works, traces of which are found in many parts of the Punjab and North-west Provinces.

The number and extent of the irrigation works of nearly all classes carried out over the length and breadth of India by native engineers, in many cases long anterior to the rise of British rule in the country, it will thus be seen, is very great. English engineers have to a large extent adopted and improved the systems they found already in operation, with the exception of the great Delta schemes of irrigation on the east coast, and the magnificent Doab perennial canals in the north, which are new classes of works of entirely English origination, the conception and execution of which, dependent on a higher degree of scientific attainments, were no doubt beyond the ability of the earlier native engineers.

CHAPTER III

Leading features of modern canal construction—Classes of canals—Irrigation and navigation: often combined in India—Main body of canal—Source of supply—'Doab' canals—Widths, depths, and slopes—Works at head of permanent canals—Dams and weirs—Scouring sluices—Protection works—Aqueducts and passage of rivers—Service bridges—Over-falls, locks, escape-weirs and drainage—Observations on proposed sketch of modern canal-systems in India—Unfamiliar character of irrigation works to the general public—Punjab irrigation—Western Jumna canals—Bari Doab Canal—Sirhind canals—Swât River Canal—Chenab Canal—Inundation canals—Sidhnai—Minor inundation canals—General results of Punjab irrigation.

BEFORE proceeding to place before the reader an outline sketch of the modern irrigation works of India, carried out by the direct or indirect agency of the British Government within the present century, a few words on the main leading features of canal construction, and the particular classes of engineering works with which canal engineers have to deal, are necessary in order that the unprofessional reader may be enabled intelligently to follow the necessarily very condensed account of such works in the following pages.

There are, then, two primary classes of canals, viz., canals for irrigation and for navigation. Obviously it is necessary that the former class should be made so as to flow with a regular current, and that they should be fed by some continuous source of water to make up for that consumed in irrigation. They should also be so located as to traverse as high ground as possible, in order that the water drawn from them may command and irrigate a large area of land, either on one, or better still, on both sides of them. On the other hand, navigation canals are, as a rule, better located at a low level, with hardly any current, so that boats may journey with equal facility either up or down

—unless, indeed, it happens from special circumstances that all, or nearly all, of the traffic is in the direction of the current only. It is, however, often necessary or desirable to combine irrigation and navigation in one and the same canal, in which case the current is kept as low as may be consistent with the wants of the irrigation. Combined irrigation and navigation canals have been very largely constructed in India, chiefly for economical reasons.

The main body of a canal consists of an artificial water channel excavated wholly in the soil, or carried by means of entire or partial embankment, at the required level, above the surface of the district traversed. The source of supply is usually some great river having a continuous and ample flow of water. Nearly all the great rivers of India, owing to the heavy deposit of silt from their waters, run on beds elevated somewhat above the level of the immediately adjoining strip of country on either side of them. In upper India this strip of lowland, which forms the valley of the river, and marks the general limits of the flood-deviations from side to side, is called the 'Khadir.' The higher table-land lying between two more or less parallel river valleys along the whole extent of their course, is called the 'Doab' or interfluvial tract—from *do* (two), and *ab* (water) —*i.e.* between two waters.

It is clear that an irrigation canal, to be of any extended use, should be carried along the highest ridge of the 'Doab' tract, and that a short cut from the nearest part of the river would only lead the water into a more or less deep cutting, from which it would have to be lifted out by pumps or otherwise. Hence to *command* the Doab—that is, to be above it, and to control it, the canal must obviously be drawn off at some convenient point on the river, situated high up on its channel, at an elevation sufficiently great to admit of the water being led down by means of the canal, and at a reasonable expense, to the desired level of the Doab table-land.

The relative widths, depths, and bed-slopes given to canals will vary, within limits, according to special circumstances, but will primarily depend on the quantity of water to be carried, the nature of the soil, and the necessity or otherwise of providing for navigation. If the bed-slope given is too great, the

bottom and sides of the canal may be torn up, or greatly worn; all foundations of bridges or other works along the canal will be endangered, and navigation against the current will be impossible, or difficult. If the slope is very little, a larger canal will be required to carry the intended quantity of water; there will also be danger of a rapid deposit of silt and growth of aquatic plants which may choke up the channel, whilst the expense of many additional works, such as overfalls or locks, will have to be incurred. It is necessary, therefore, that a nice adjustment be made in each case, according to a continually varying set of circumstances and conditions; the ultimate success or failure of the canals, both constructionally and commercially, being entirely dependent on the care taken in these particulars.

The heaviest works in connection with canals are usually at or near their heads, and at those places where the rivers of the country, which cross the intended line of canal, have to be disposed of. The works at the head of permanent canals most commonly consist of masonry dams or weirs across the supply-river for holding up the water in a pond or pool above them, and a 'regulator' or set of movable sluices across the mouth of the canal, which is drawn off from the pool, by means of which water can be admitted into the canal or shut out.

Dams, when they are made solid, are generally called 'weirs.' True dams are provided with a regular series of piers and openings in their central portions, the latter capable of being wholly or partially closed. Solid weirs require to be provided with sluices fitted at a low level to keep up a scour, and prevent the accumulation of deposit in front of the canal regulators situated above them. For properly effecting this purpose they are usually built in that part of the weir nearest to the canal head. In long weirs one or more lines of scouring sluices are sometimes provided in the middle portions of the weirs.

Extensive works to prevent the extremities of a weir or dam from being turned by the river when in flood, such as massive and lengthy revetment-walls, wing-walls, and embankments, are very frequently required, especially where the river banks are low, as well as protection embankments and training works to prevent the adjoining lands being flooded, and to keep the river in a fixed course.

After the canal has left its supply river, the next difficulties encountered are generally in connection with the natural water-courses of the country which intersect its alignment. Sometimes the canal is carried over these water-courses—or it may be wide rivers—by means of more or less long and elevated aqueducts; some of which may be of very great size. Sometimes it is passed under the rivers by a syphon aqueduct. At other times the river itself is carried by a bridge or 'super-passage' over, or is syphoned under the canal; or if this cannot be done, the river is made to cross the canal on a level, the two waters being allowed to mingle together. In this case special works are provided to control the movement of the combined water, and direct it as required.

In Upper India the first portion of most of the larger canals, derived from the Himalayan rivers near the point of their exit from the hills, have to cross—whilst traversing the low 'Khadir' or valley land—in one or other of the above ways, many rapid, and when in flood, violent mountain torrents; but when once the canals reach the level of the Doab table-land, their course henceforward lies generally on a ridge between the principal rivers, and they encounter few serious obstructions. In proportion to the activity and population of the districts traversed, canals have to be provided with a greater or less number of service bridges, or other means of passage from bank to bank; these crossings are often necessary at very frequent intervals, and form no inconsiderable item in the total cost of the irrigation.

In the upper parts of Doab canals especially, where the slope of the natural ground is very much greater than it would be proper or possible to give to the canal beds, and where the width and depth of the canals is at a maximum, arrangements have to be made to compensate for the excessive slope. This is done by laying out the bed of the canal in a series of *steps*. The points where the bed is let down from a higher to a lower level are called 'falls' or 'overfalls,' and it is evident that such falls must be constructed of masonry, or other durable material strong enough to withstand the wearing action of the water. Often for reasons of economy, or on other grounds, the position of a 'fall' is made to coincide with some bridge,

super-passage, or other necessary work. Overfalls are made in a variety of ways; sometimes they are vertical, and are provided with gratings arranged like the teeth of a comb, to break the force of the water, and with cisterns to act as water-cushions below them, or they are made in a curved or 'ogee' form, so as to deliver the water at the lower level with as little violence as possible. These works on some canals are often of considerable magnitude and cost. Locks, escape-weirs, and channels for discharge of surplus waters are also frequently required, as well as extensive drainage works in some instances, to prevent the adjoining country being made swampy and unhealthy.

Such are some of the chief classes of construction met with on irrigation and navigation canals. In the outline sketch of the various canal systems of India which follows, it is obvious that considerations of space will not permit a detailed notice of more than a few individual works; but the reader will now be in a position to follow and understand the general references made to these works which he will meet with. Our task in the following pages is to convey to the reader, in the smallest possible compass, a clear idea of the very great mass and value of the irrigation works of India, which have been carried out up to the present time by the British Government. Unhappily for our purposes, irrigation works are almost completely outside the knowledge and acquaintance of the general public. Unlike the fine works constructed all over the country in connection with railways, for instance; the magnitude and utility of which in course of time and travel, have become more or less familiar to the eye and knowledge of thousands, the splendid examples of engineering constructions executed for the provision, control, and distribution of the huge volumes of water required to fertilise the ever-thirsty fields of the country, are in general situated far from the main lines of public traffic, are more or less entirely hidden from popular view, and are familiar only to those whose duties or interests may be in one way or another connected with them. Vastly important as large irrigation works are, and interesting as feats of engineering skill and daring—scarcely second indeed to railway operations, they nevertheless embody a class of works which, as a whole,

appeal far less forcibly to popular imagination than those connected with railways, owing in great measure, no doubt, to this relative unfamiliarity. The works we are about to sketch, in mere skeleton outline, embody an enormous aggregate; yet large as this aggregate undoubtedly is, it represents but a fraction of what is becoming more and more desirable, in order that the agricultural operations and productions of India may keep pace with the general advancement in other directions.

ıjab Irri-
ion.

The Punjab system of provincial canals contains the first irrigation work undertaken by the British Government, which was the restoration of Shah Jehan's old Delhi branch-canal. About the year 1753 this branch—taken off, as we have lately seen, in 1626 by Ali Murdan Khan, from Feroze Shah's old line to Hissar—ceased to flow. In 1817 the British Government appointed Captain Blane to restore it, and in the year 1820—after a closure of about sixty-seven years—water was again introduced into Delhi; irrigation having been commenced during the previous year.

stern
nna
ıals.

A few years later, viz., in 1823, the restoration of Feroze Shah's original canal to Hissar was commenced, and during the next twenty years the system now known as the 'Western Jumna Canals' was fully developed. The head of the main channel was situated on one of the numerous side streams into which the Jumna is divided as soon as it issues into the plains from the Sewalik, or sub-Himalayan range. Here, by deepening the channel, and by running out spurs or dams either partially or completely across the main stream, the water used to be intercepted. The dams or spurs were rudely constructed of boulder stones and coarse gravel, taken from the bed of the river; the smaller materials being packed into cribs or frames of basketwork. The intercepted water was first led by an artificial cut into the Putralla river, and then along the bed of that stream as far as its junction with the Sombe. In order to pass the canal water beyond the latter river, a permanent masonry dam 777 feet long, in place of the old earthen dam which was formerly employed, and which had to be annually reconstructed, was substituted in the year 1833.

The foundations of the dam consist of masonry blocks sunk eight to eleven feet into the river-bed under the piers. The

blocks are connected on both up and down stream sides, by lines of curtain works, and the floor is formed on flat arches abutting on the pier foundations. Both above and below the dam there is an 'apron' or slope formed of stone, and rough masonry, retained by timber piles driven closely together. Beyond this piling, on the down-stream side, is another flooring of river stone, packed in cribs, and secured against movement by another line of smaller piles. The floor stretches across the bed of the Sombe, with abutments twelve and a half feet high on each side. The whole width is divided into sixty openings of ten feet each, by fifty-nine piers six feet in height and three feet wide. The banks of the river are well protected by long revetment walls—that on the west side, 750 feet long, connects the dam with a bridge across the canal. The overfalls are made to diminish in height towards the centre, with the object of keeping the strength of the current in the middle of the river, and prevent its setting along either of the abutments. The piers are furnished with grooves to receive the sluices.[1] The peculiar position of this dam and dependent works at Dadupur, near the confluence of several torrents, all liable to severe and violent floods, and having no established beds, has exposed them to many dangers, which have called for the greatest vigilance in maintaining them. The canal, once extricated from these rivers, is carried on its course with comparative ease. The main Western Jumna canal may be said to commence at the Dadupur dam. As far as Karnal it was originally carried along the low land of the Jumna river, soon however gaining the level of the higher country to the westward, where it presently divided into two branches; one carrying the water to Hansi and the other to Delhi. During comparatively recent years the Western Jumna system has been completely remodelled, in order to remove the evils due to its originally defective and low position, which caused a good deal of unhealthy swamping of the country along its course, also to increase the volume of water, to extend and regulate the distribution, and to improve the navigable character of the main channel.

[1] *Vide* Colonel Baker's Report on the Western Jumna Canals.

In 1864 an investigation into the condition of the canals was ordered, many plans for their improvement were suggested, but a definite scheme was not sanctioned until the year 1874. The main features in the alterations of the older works carried out, were, the construction of a permanent weir and head-works on the Jumna; a new main line of canal taken off from the old channel 15 miles above Karnal, extending as far as the Delhi branch, in place of about 50 miles of lower and very defective line, and a new channel along 55 miles of the Delhi branch itself, together with a considerable extension of distributing channels and various drainage works.

At the head the main canal is 360 feet wide, decreasing gradually to 120 feet as water is drawn off. The total length of the Western Jumna main and branch canals is 280 miles, of which 243 miles are navigable, with over 900 miles of distributing channels, irrigating in good years about 550,000 acres. It is said that during the terrible famine of 1837-38 the value of the crops saved by its waters was £1,462,800, supporting the inhabitants of 500 villages, who would otherwise probably have died of starvation. From the beginning it has been an exceptionally remunerative undertaking. At the end of the year 1890-91 the accumulated net profits at credit of the canal amounted to very little short of three millions sterling.[1] An important new branch taken off from the main channel about the 45th mile, and running to Sirsa, has lately been commenced. This branch will be 138 miles long, with 500 miles of distributaries, irrigating about 175,000 acres.

Very soon after the annexation of the Punjab in 1849 a project for providing irrigation in the arid districts lying between the Ravi and Beas rivers was taken up by the Government. As previously mentioned, in this district, known as the 'Bari Doab,' an old native canal existed, constructed in 1633 under the Emperor Shah Jehan, called the 'Husli' canal. Although constructed primarily for the supply of water to the royal gardens at Lahore, the channel served to irrigate a certain area situated in the upper part of the Doab; but its course was generally so defective that no use could be made of it in the

[1] Revenue Report of the Irrigation Department, Punjab, 1890-91.

alignment of the modern 'Bari Doab Canal,' although small portions of it have been incorporated in the distributive system.

The 'Bari Doab Canal,' as now existing, was commenced in the year 1850, but progress on it was much delayed by various revisions and alterations of the original project. A few miles of the present system was opened in 1859, but up to the year 1868 no permanent head-works had been constructed, and only a comparatively small portion of the main and branch canals were completed. The system has, in fact, been gradually developed almost up to the present time. The head of the canal is situated on the Ravi at Madhopur, where the river issues from a low portion of the Himalayan range. Here, in 1868, the construction of a permanent weir was commenced, which was completed in 1873. The bed of the river at Madhopur is composed of boulder stones of large average size, and the fall is 26 feet per mile. With such a heavy inclination as this the velocity and force of the current is of necessity exceedingly great.

The weir consists of two parallel walls of masonry 35 feet apart and 5 feet high, the intermediate space being filled in with boulders set in cement for a thickness of 3 feet, and there is a long protective apron or slope of boulders below the down-stream wall. The weir was constructed straight across the river at right angles to the direction of the current, but this was subsequently found to be a mistake, as, owing to the nature of the river bed the scouring sluices provided in the body of the weir failed to keep up a sufficient scour, so that the boulders rolled along by the rapid current were banked-up to the top of the weir-wall, almost across the whole width of the river, and the deep-water channel near the canal entrance could hardly be kept open. This, and other experience, has taught canal engineers that dams or weirs across boulder streams having a great inclination of bed should be made obliquely to the line of the current. At Madhopur the difficulties imposed by the original faulty alignment of the weir have by various remedial measures been now largely surmounted.

The canal entrance is provided with regulating sluices, and the canal, 120 feet in width, is led away from the river through

a deep cutting in the high bank of the river. In the first few miles of its course it crosses two mountain-torrents, after which it soon gains the table-land between the Ravi and Beas rivers. At the 30th mile a main branch diverges and carries the water to Kasur, near Ferozepur, and from the upper part of this branch another is carried nearly parallel with the Beas to a point opposite Sabraon, near the junction of the Beas and Sutlej. At the 55th mile the Lahore branch is taken off, and extends to Mean Meer and Lahore. The main canal itself, after traversing the central part of the Doab, tails into the Ravi some 60 miles below the last-mentioned town.

The Bari Doab system of canals has a total length of main line and branches of 362 miles, with 1048 miles of distributaries, commanding an irrigable area of 535,000 acres, or 836 square miles. The estimated value of the crops annually irrigated by it now amounts to over £1,600,000. The financial results of working the canal during recent years exhibits a steady advance.

Sirhind Canals. The tract of country lying between the upper waters of the Jumna and Sutlej rivers contains the watershed or ridge line of division between the Indus and Ganges basins. This watershed lies much nearer the Jumna than the Sutlej, and the space between it and the latter was once watered by the Ghaggar, the ancient Saraswati, a river which, in its higher portion, has been for a long time unpleasantly familiar to all visitors to Simla. The Ghaggar formerly flowed through the heart of the country, from the mountains to the Indus, near Rori, in a direction almost parallel with the Sutlej; but its vast lower beds, locally known by the names of 'Hakra' and 'Sankra,' have long been dry hollow wastes. The water in the modern river, even after the heaviest rainfall, is soon swallowed up in the ever-encroaching desert sands to the southward.

In this almost rainless region, comprising the districts of Ludhiana and Ferozepore and the native States of Puttiala, Jind, and Nabha, west of the Ghaggar, the want of water for purposes of cultivation was extreme. In the year 1840 Captain (afterwards Sir William) Baker took a line of levels across the country from Karnal to Ludhiana. He found that the greatest elevation of the watershed between the Jumna and the Sutlej

(lying comparatively near the former river) was 68 feet, and after further preliminary investigation he ascertained the perfect feasibility of conducting water from the Sutlej into an immense culturable area, then almost a dry desert. Nothing at this time, however, was done, owing to various causes, but chiefly owing to the difficulties imposed by the intervention of several native States, which would have to be traversed by the canals proposed. Twenty years later the project was revived, mainly on solicitation of the Maharajah of Puttiala, who, so far as irrigating his own territory was concerned, offered to defray all expenses connected with the preliminary investigation and survey, whether the scheme proved practicable or otherwise. In the year 1869 the matured project for the existing 'Sirhind Canals' was finally settled, the upper portion of the works was commenced, and in 1873 an agreement with the several native States interested was concluded. The main features of this agreement were, that the work was to be designed and carried out by the British Government, and that the entire cost of the main canal and preparation of the project was to be borne by that Government and the native States, in proportion to the quantity of water allotted to each. As regards the branches and distributing channels, each party was to bear the cost of its own portion. The management of the main canal and branches was to rest with the Government of India, but each party was to have entire charge of its own distributaries, and defray all expenses of maintenance in proportion to the share of the water supply allotted in each case.

The Sirhind canal system as carried out consists of a short trunk canal drawn from the Sutlej at Rupar. At the 41st mile a division of the water is made; one main branch extending westwards to Ferozepore, mainly for the supply of water to British territory, and another main branch south-eastwards to Puttiala, principally to supply the wants of the native States of Puttiala, Jind, and Nabha. Numerous secondary branches extend from the above, roughly parallel with each other, in a south-westerly direction, carrying the water-supply nearly as far south as Sirsa, and to the upper border of the Bahawalpur State on the west. The trunk and main branches to Ferozepore and Puttiala respectively are navigable, and a navigable exten-

sion, 55 miles long, through the watershed, from a little below Puttiala to a point on the Western Jumna Canal above Karnal is contemplated, which will form a junction between the Punjab and Bengal systems of inland navigation, through the Delhi connection with the Agra canal in the North-west Provinces.

As usual in the case of canals drawn from rivers not far from where they issue from the mountains, the heaviest portion of the works on the Sirhind canals lies in the first few miles from the head, where the channel has to cross several mountain torrents which intersect the Sutlej valley. A masonry dam or weir is constructed across the Sutlej nearly opposite the town of Rupar, and just above the weir a regulating bridge crosses the commencement of the main canal, 200 feet in width. The canal is carried through a hill spur in a cutting 45 feet deep in the highest portion, and with an average depth for about nine miles of 28 feet. The cross drainage of the valley is conveyed over the canal by two large masonry over-passages. Prison labour was very largely employed on this portion of the works.

The total length of main-line and branches is 542 miles, with 4385 miles of distributing channels. 189 miles of the canals are navigable, of which 143 are British, and 46 are in native States. The system commands an irrigable area of over 800,000 acres, or 1250 square miles of cultivation.

Swat River Canal.

The only remaining perennial canals in the Punjab are the 'Swât River Canal,' and the Chenab Canal, the latter a very recent work, as yet only partially developed, for irrigating the 'Rechna' Doab, lying between the Chenab and Ravi rivers. The Swât River Canal is a small work, 22 miles long, with 140 miles of distributing channels, situated in the north-east corner of the Peshawur valley, where the rainfall is exceedingly small and uncertain. The canal, which was commenced in 1876, is drawn from the Swât river, above a dam constructed not far from the frontier post of Abuyaee, where the river issues from the mountains. It irrigates an area of about 89,000 acres out of 120,000 acres commanded.

Chenab Canal.

The Chenab system of irrigation in the Rechna Doab, which, when fully developed, will be the largest and most important

in the Punjab, is derived from the river Chenab, over which a fine permanent weir, with connected canal head works at Khanke, a few miles below Wazirabad, has quite recently been completed. The main canal (hitherto, pending the completion of the head works, worked as an inundation canal) is carried down the high land of the Doab, passing close to the town of Hafizabad, irrigation commencing within a very short distance of the head. The area irrigable by the existing project is 400,000 acres. The length of main channel and branches was in 1891 91 miles out of 125 projected, with a length of completed distributaries of 283 miles out of 529. It is under proposal to double the capacity of the present main channel, to enable the full power of the new head works to be utilised, the effect of which will be to very largely extend the irrigable area, viz., from 400,000 to over a million acres, or 1563 square miles, at a cost of about a million and a half sterling (150 lacs of rupees).

A great number of Inundation Canals have from very early times been in operation all over the Punjab Province. Under systematic administration these canals as a whole may be ranked as amongst the most remunerative irrigation works in India, although from the unavoidable irregularity and uncertainty in their supply of water, they are of far less certain value to the cultivators than the perennial canals. The greater portion of the inundation systems now in operation under the management of the Government of India Irrigation Department, are based on old native constructions, which have been enlarged, restored, or improved, by English engineers since the year 1849, others are of entirely British origination. The lower Sohag and Para canal is drawn from the right bank of the Sutlej, about 50 miles below Ferozepore. It has 95 miles of main channel and branches, with about 40 miles of distributaries, and an irrigable area of 93,000 acres; the area annually irrigated varying greatly, according to the season, as is the case with all this class of irrigation works. Inundation Canals.

An interesting example of one of these canals of recent British construction is the 'Sidhnai' taken from the lower part of the Ravi near its junction with the Chenab. Owing to the small depth of water in the Ravi at the time of year when it is Sidhnai Canal.

chiefly required, it was found necessary to construct a dam to head up the water. Subsequently a lock to provide for a small amount of river navigation was added. The dam has been constructed on a principle borrowed from a French source, called the 'needle' system. In this system the level of the water on the up-stream side of the dam is raised or lowered as required, by the insertion or removal of a line of vertical timbers called 'needles;' each needle being 7 feet 6 inches long, with a handle 18 inches long in continuation, and 5 inches by 3½ inches in section, weighing about 40 lbs. The needles are made to abut closely the one against the other, in a slightly inclined position, resting against a timber beam above, the lower end falling into a notch cut along the crest wall of the main dam. The insertion or removal of the needles is effected from a small foot-bridge, provided with rails for the passage of trollies. The masonry dam is 737 feet long, and is divided into bays or spaces of about 20 feet each, by dwarf piers which serve to support the upper beam against which the needles rest, and to carry the small rail-bridge.

By closing up, pushing forward, or bodily removing a sufficient number of the needles in any or all of the bays, the level of the water in the river above the dam is maintained at the height required to feed the canal, which is drawn off through a regulating bridge with sluices above the dam. The canal was commenced in 1884, and the whole irrigation system was in full operation in 1887. The main channel at its head is 80 feet wide, and 6 feet in depth at full water, and has a slope of 1 foot in 8000 feet. The length of main line and branches is 58 miles, with 146 miles of distributing channels, irrigating an area of about 122,000 acres. From the very commencement the work has proved exceptionally remunerative. In 1891, the balance of net revenue to the credit of the canal, after paying interest charges, amounted to over £25,000, after but little over four years of actual operation. The remaining systems of minor inundation canals in the Punjab are the 'Upper Sutlej series,' derived from the right bank of the Sutlej below Ferozepore; the 'Lower Sutlej and Chenab series' near Multan; the 'Indus' and 'Muzaffargarh' series, and the 'Shahpur' series; the latter drawn from the left bank of the Jhelum. These

groups of canals have an aggregate length of main line and branches of 2605 miles, with 591 miles of distributaries, irrigating about 1,016,000 acres, or 1558 square miles.

General results Punjab Canals.

As commercial undertakings the irrigation canals in the Punjab have been very successful. In the whole Punjab Province the total expenditure by the British Government on such works, up to the end of the year 1890-91, amounted to £6,435,818, in addition to a further sum of £1,402,450 contributed by native States. The total mileage of completed main and branch canals was 4058 miles, with 7545 miles of distributing channels, of which 223 miles of main channel and 1940 miles of distributaries are in native States. Of the main channels 432 miles are available for navigation. The perennial canals, in the year 1890-91, irrigated an area of 2601 square miles, and the inundation canals irrigated 1840 square miles. The whole area irrigated was therefore 4441 square miles of cultivation, and the estimated value of the crops raised by canal irrigation throughout the Punjab in the same year reached the enormous total of £8,815,777. On the seven large 'productive' works constructed by the British Government, the percentage of revenue earned to capital outlay was 5·91 per cent., and the net surplus of revenue for the year, after deducting all interest charges, amounted to £132,747. The accumulated balance of net revenue at the credit of the system of productive canals in the province, for which interest accounts are kept—principally due to the valuable Western Jumna system—was £2,203,187, and including all the inundation canals £2,926,936.[1]

[1] For details of individual works in the Punjab *vide* Appendix A.

CHAPTER IV

NORTH-WEST PROVINCES

North-west Provinces irrigation—Eastern Jumna Canals—Ganges Canal—Inception—Head works—General course followed—Branches—First twenty miles—Slope of the country—Ramipore torrent—Superpassage—Patri River superpassage—Rutmoo torrent—Solani valley and aqueduct—Aqueducts and ordinary bridges compared—The Solani torrent—General description of aqueduct—Embankment—Masonry revetment walls—Execution of earthworks—First locomotive engine used for constructional purposes in India—General description of the Solani River crossing—Details of construction—Piers and abutments—Foundation works and arching—Completion of Ganges Canal—Opening by Lord Dalhousie—Subsequent remodelling of canal.

North-west Provinces Irrigation—Eastern Jumna Canal. In the North-west Provinces the earliest work undertaken by the English Government was in connection with the Eastern Jumna Canal. This canal, which, as we have seen, was originally constructed by Ali Murdan Khan, under the Emperor Shah Jehan, was abandoned in 1628 shortly after its construction, owing to the excessive slope of the bed and the difficulty of maintaining its passage across the mountain torrents near its source. It is said to have been partially restored in 1764 by a chief named Zabitha Khan, but again fell into disuse. The canal was re-opened under the British Government in 1830; the work of improvement having been commenced in 1823. The original defect of excessive slope, however, soon again made itself apparent, and to remedy this, the construction of a series of masonry over-falls, to correct and regulate the slope of the bed, was constructed. A portion of the canal was again remodelled in 1854. A new cut of more than 5 miles in length was excavated, and the adjustment of the bed slope was finally completed.

The head of the Eastern Jumna canal is about 3 miles

below that of the Western Jumna system, on the opposite bank of the river. For the first part of its course it occupies the shingly bed of the Budhi Jumna for 4 or 5 miles to Nayashahr, where a masonry dam with 30 sluices was constructed across that stream. It then enters a difficult tract of country, having to cross on the level four mountain torrents within a distance of 10 miles. Two of these, the Nowgong and the Muskarra, are wide and rapid, and are furnished with masonry dams to regulate the flood waters. On gaining the high ground between the Jumna and Hindun, the canal continues nearly parallel with the former river, and only a few miles distant from it, until it again re-enters the parent stream at Delhi. For a length of about 40 miles the canal is carried on embankment from 6 to 12 feet above the level of the country. Its length is 130 miles, with 640 miles of distributing channels, watering a tract about 120 miles long and 15 miles broad. The canal commands a culturable area of 589,000 acres, of which 350,000 acres are irrigable by the present channels. The Eastern Jumna is one of the best-paying canals in India, returning a very high percentage on the capital expended upon it by the British Government, which, however, is short of the full value of the work, by whatever sum may be assigned as the value of the old native works utilised.

Encouraged by the favourable results of the Western and Eastern Jumna canals, the English Government of India took up in a large and liberal spirit the consideration of numerous irrigation projects. In the year 1836 the first studies for a large original canal to be derived from the Ganges, for the irrigation of a considerable portion of the Ganges Jumna Doab, were made, and the supreme necessity for such a work was terribly illustrated by the fearful loss of life and sacrifice of revenue entailed by the calamitous famine of the following year, 1837-38. Complete investigation and detailed surveys and estimates for various projects were made, and exhaustively discussed, labours which eventually resulted in the well-known Ganges Canal. Ganges Canal.

When this magnificent scheme, which was practically commenced only in 1848, was, after various vicissitudes, completed in 1854, it was the largest work of the kind in existence in the

world. Even at the present time there are few canals that can compete with it in boldness and originality of conception, and although the original design and execution of the work in some important particulars was almost of necessity injuriously affected by the absence, at the time of its projection, of previous experience in canal-engineering on anything like so large a scale, it still remains one of the most remarkable public works of its class to be found in any country. The early history and minute description of its engineering details, written by its able designer and constructor, Sir Proby Cautley, has rendered it also perhaps better known to those specially interested than almost any other similar work.

The Ganges Canal commences at Myapore, at a short distance below the sacred town of Hardwar, almost at the point where the Ganges river, forcing its way through the 'Sewalik' sub-Himalayan range, debouches into the plains. A little above Hardwar the Ganges divides into two branches, which again unite about a mile and a half below the town. The canal is taken off from the southern, and smaller, of these two branches, which is carefully regulated and kept clear to feed the canal.

A permanent masonry dam, provided with sluices, is thrown across the river branch. This dam is 517 feet long between the flanks, and is pierced in the centre by fifteen openings, each 10 feet wide. The piers, which are 8 feet high, are fitted with grooves for the sluice-shutters. On either side of the central openings are overfalls of stepped masonry 18¾ feet in maximum height. A tramway, provided with a travelling crane for working the sluices, extends along the top of the dam, and is a later addition. At the entrance to the canal is a regulating bridge of ten openings, each 20 feet wide, furnished with sluice-gates, which can be raised or lowered by means of capstans. The bridge, besides serving to carry the canal head sluices, carries the public roadway from Hardwar to Kunkhut.

By means of the two sets of sluice-gates, viz, those in the dam, and at the regulating bridge, either the whole amount of water in the river branch can be intercepted and sent down the canal, or the whole, or any part of it, can be shut off from the canal, and allowed to escape through the dam, to rejoin the main Ganges river below.

From the regulating bridge the canal flows in one continuous stream for 180 miles, with a bottom width at the commencement of 140 feet, and not far short of 200 feet on the surface of its full water, diminishing gradually to 80 feet bottom width at the 181st mile. Here the canal bifurcates into two separate canals; the point of bifurcation being provided with a regulating bridge fitted with sluice-gates, precisely similar to that at Myapore, to control the quantity of water passed down either branch. One of these branches, 170 miles long, and navigable throughout, extends with a gradual reduction of width to 20 feet, to Cawnpore. Passing between the cantonment and the city, it re-enters the Ganges through a series of locks and gates, adapted for the entrance and exit of boats. The other branch, also after a course of 170 miles, and a gradual reduction of width to 20 feet, passes into the Jumna near Hamirpur.

For the first 20 miles of its course from Myapore to Roorkee, the main canal passes over the 'Khadir,' or low valley land of the Ganges river, and is taken across a number of large mountain streams, subject to sudden and violent floods, which descend from the neighbouring sub-Himalayan range of hills. Along this tract of apparently level country the slope of the ground is in reality so great that the beds of these streams for the greater part of the year consist only of dry sand and shingle, but during the rainy season they become wild and foaming torrents. 'To carry the great canal—itself a small river—across such a country—to see it pass silently on, uninterrupted and uninjured by these torrents, while the torrents themselves pass through the canal unchecked, as well as over it, and under it in several places—is a triumph of art and engineering ability.'[1]

About 6 miles from the head works, the Ramipore torrent is passed over the canal by a masonry aqueduct or 'superpassage.' This aqueduct carries a volume of water 196 feet wide and 14 feet deep. The canal passes below through eight arched openings, each of 25 feet span, on the up-stream side of which a masonry overfall of 9 feet carries the canal to a lower

[1] 'Public Works in the Bengal Presidency,' by Major-General B. H. Tremenheere. *Minutes of Proc., Inst. of Civil Engineers*, vol. xvii.

bed. On the left there is a lock and channel, by means of which boats can pass round the aqueduct. In the 10th mile the Patri river is conveyed across the canal by a grand aqueduct, similar to that at Ranipore, but on a still larger scale; the width of waterway for the river being no less than 296 feet, carried on nine arches, extending the whole width of the aqueduct. The canal passes beneath through eight of these arches, and a curved masonry line of descent on the up-stream side carries the water to a 9 feet lower level. The ninth arch opening is utilised for the lock, bringing the navigable channel down to the same extent.

In the 13th mile the canal meets the Rutmoo torrent on the same level with itself. The flood-water of this torrent, which carries the drainage of 126 square miles of country, and which has a bed-slope of 8 feet in every mile, is allowed to mingle with the water of the canal. It is admitted through an inlet-dam, consisting of a masonry platform provided with regulating sluices, and it passes out over another masonry escape-dam, situated opposite the inlet one. The torrent is only passed completely across the canal during the period of highest floods, when communication with the lower portion of the canal is shut off to the extent required, by the flood-gates of a regulating-bridge just below the cross-passage. At such times the flood-waters of the torrent, and the head-water of the canal itself, both pass over the escape-dam, and are carried away down the lower channel of the torrent. The escape-dam is provided with 47 sluice-openings, each 10 feet wide, separated by piers $3\frac{1}{2}$ feet thick, the bottom of the sluice-openings being flush with the bed of the canal. On each side of the central portion there are five additional sluices of the same width, viz. 10 feet, but having the bottom, or 'sill' of the sluices placed 6 feet higher. Beyond these higher sluices, on each side, a masonry platform extends at a height of 10 feet above the canal bed. Up to 6 feet in depth of water, therefore, there is a free passage 470 feet wide. Above this, up to a height of 10 feet, the width of the free passage is increased by the ten higher sluice-openings to 570 feet, and if the water should rise higher than 10 feet it passes over the whole width of the masonry platform, with a total waterway 800 feet long.

In the 16th mile of its course from the head-works at Hardwar, the Ganges canal encounters the Solani valley and river, at the very extremity of the low 'Khadir' land of the Ganges, and just before it gains the high ground of the Doab, a short distance beyond Roorkee. This valley is crossed on a magnificent aqueduct, having a total length of nearly 3 miles, a work which at the time of its construction was the most considerable then attempted in India.

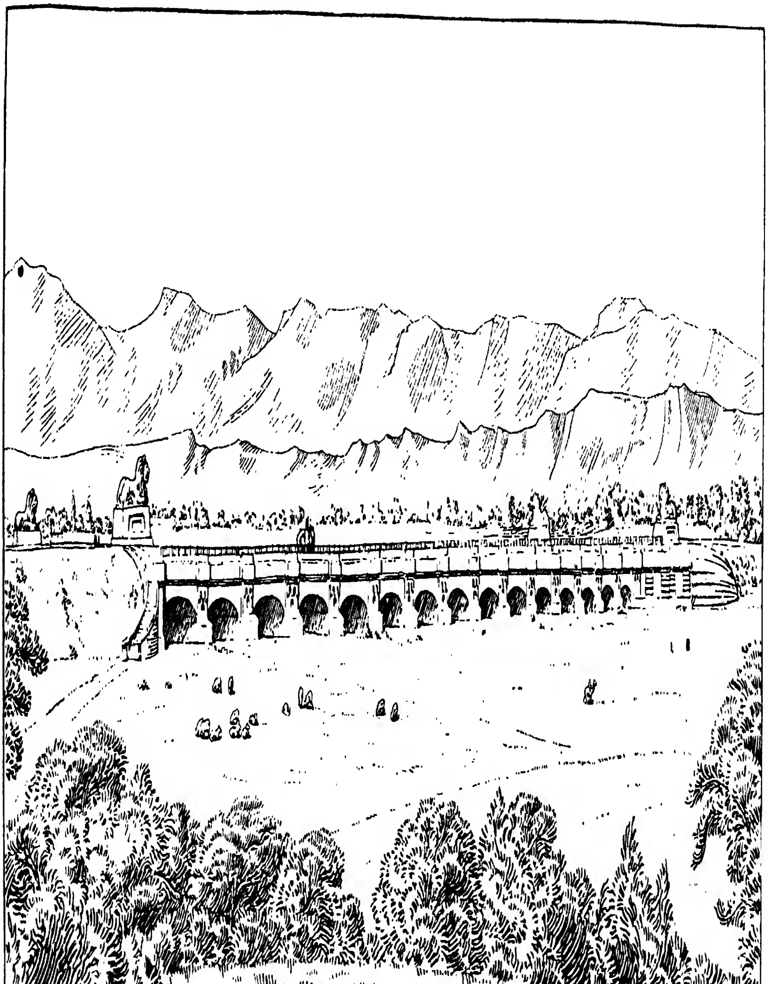
A canal aqueduct differs in no way from an ordinary bridge, except that it has to carry a water-channel over it, instead of a road or railway. It is often of much greater width than other kinds of bridges, and it is obvious that the carriage of a volume of water, probably of considerable depth, and exerting considerable pressure, requires that the side walls or parapets, which in this case support the water, should be made much thicker than those required for road or railway bridges. Special precautions also are necessary to prevent leakage in every part of the structure. The term 'railway-bridge,' or 'road-bridge,' is usually confined to the masonry or iron structure crossing the ordinary water-channel of the river; but it is usual in the case of canal 'aqueducts' to include in the term, not only the real bridge spanning the water-channel, but also the whole length of the approach embankments across the river valley, where these are carried at a considerable elevation above the natural ground. The reason of this is, that in the case of railway or road-bridges, the raised approaches on either side crossing the valley of the river, are usually plain earthen embankments; whilst in the case of canals, the embankments are commonly lined with masonry throughout their entire length, or some other special expedients are adopted to prevent the percolation and escape of water through their sides.

As we have already seen, when a canal meets a natural river, and it is necessary that it should be carried forward beyond it, it must either be conducted *over* the river on a raised bridge or aqueduct, or it must cross on the *level*, or it must be carried by a syphon or tunnel *under* the river. The adoption of one or other of these expedients will chiefly depend upon the relative necessary levels of the water in the canal and the river, at the point of their intersection.

The Rutmoo torrent in the 13th mile having been passed on the level, in the manner lately described, the Ganges canal is carried through the 'Peeran Kulliar' ridge, in a deep cutting 40 feet deep from the canal-bed to its highest point, and nearly two miles long. On emerging from this cutting, the passage of the Solani valley and river commences. The Solani is a mountain torrent of considerable size, draining an area above the aqueduct of about 216 square miles; the drainage basin being about 27 miles long and 8 broad. About a quarter of the area lies on the Sewalik range of hills, and the remainder on rapid but gradually decreasing slopes. At the site of the aqueduct the fall in the bed of the river is 5 feet a mile, and at highest floods the torrent discharges 35,000 cubic feet of water per second. The width of the river valley at the point where it is crossed by the canal is 13,265 feet, or a little over $2\frac{1}{2}$ miles; and the total length of the masonry works of the aqueduct required to convey the canal over it, from one extremity to the other, is 15,698 feet, or within a few feet of 3 miles. The Ganges canal on meeting the valley is 140 feet in bottom width, with side slopes of $1\frac{1}{2}$ to 1, carrying a body of water having a maximum depth of 10 feet.

Essentially, the works constructed to enable these large natural and artificial water channels safely to get clear of each other, consist of a massive masonry bridge or aqueduct having fifteen arched openings of 50 feet each, carrying the canal at a height of 24 feet above the river bed, and two masonry protected earthen embankments, which connect this structure with the high land on either extremity of the valley; the masonry protected embankment on the south or Roorkee side of the river being 2733 feet, or over half a mile long; and that on the north side being 10,713 feet, or over two miles long. In addition there are various works for the regulation of the river during floods, to prevent it wandering beyond its assigned limits, and for the proper control of the water flowing over the masonry aqueduct itself.

The general design of the Solani aqueduct will be gathered from the adjoined illustration and figures. It is not only one of the largest works of its kind in India, but taking into account the early date of its construction, it may be considered



SOLANI AQUEDUCT.

as the most interesting and remarkable modern structure in that country. The total elevation above the river-bed is 38 feet only. Owing to this deficiency of height, as compared with length, the aqueduct as seen from below is by no means specially imposing; but when viewed from above, where its immense breadth and solidity are apparent, with its line of masonry-channel extending for nearly 3 miles, the effect is most striking.

Work was commenced on the earthen embankment lying north of the river in the cold season of the year 1845, and the whole aqueduct was practically completed by the year 1854. During the first two years much time was of necessity expended in manufacturing the enormous quantities of bricks and other materials required for the masonry; in collecting the necessary working-plant, and in bringing together, organising, and in great measure educating, the skilled labour needed, which at that time was greatly, if not almost entirely, wanting.

The height of the earthen embankments on the north and south sides of the river, from the surface of the natural ground up to the bed of the canal, is variable, but averages about 16 feet over its entire length, and reaches a maximum height of 24 feet. Above the level of the canal bed, the two portions of the bank forming the canal sides, rise to an additional height of 12 feet, the width of each being 30 feet on the top. The total height of earthwork, therefore, averages 28 feet, with a maximum of 36 feet. At the level of the canal bed the embankment is 290 feet wide, reaching 350 feet in width on the lowest ground surface.

Longitudinally through the whole length of the embankments, masonry walls, at a distance apart of 150 feet (or the width of the canal), are carried. These walls are founded in the natural ground, and are built up to above the highest water level in the canal, they are entirely concealed in the earthen embankment, except the inner portions lying above the canal bed. This portion is worked back into a series of steps, which form the interior sides of the canal, along which the water flows. The internal construction of the aqueduct embankments, with the enclosed revetment-walls, will be best

understood from a glance at the figures 1 and 2 below, which represent an embankment and wall cut open from top to bottom, on lines drawn across them—or what are called 'cross sections.'

FIG. 1.

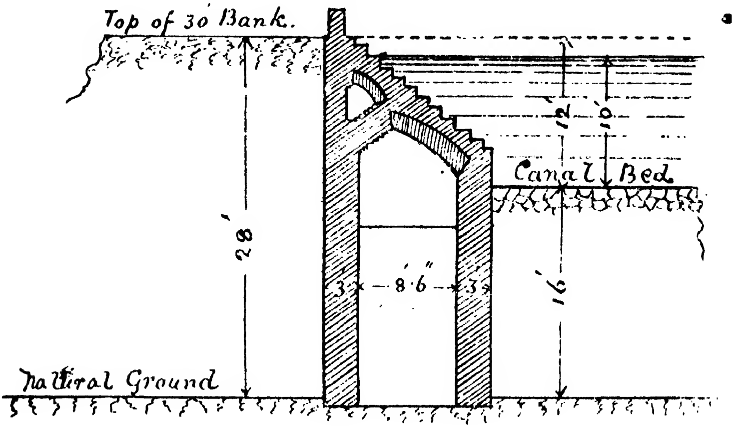
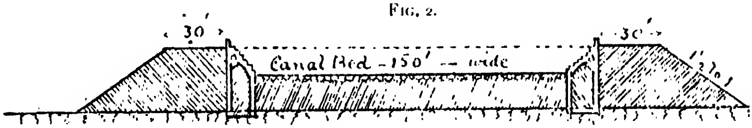


FIG. 2.



It will be observed that each line of revetment is formed of double walls of masonry 8 feet 6 inches apart, and 3 feet thick; the two walls being joined together above by archwork, arranged so as to admit the super-construction of the series of steps forming the actual revetment of the canal sides. The pair of walls forming the masonry heart of the embankment are also joined together at intervals of every 15 feet of their great length of more than twice $2\frac{1}{2}$ miles, by cross walls built up nearly to the level of the canal bed. All the hollow spaces between the brick walls, and up to the under side of the archwork is filled in with earth or clay, well beaten down, which formed, in fact, the 'centering' or support on which the archwork was built.

The earthwork of the embankment was executed in a variety of ways. On the early commencement of the work on the north side of the river in 1845, earth was dug from side trenches 188

feet wide and $5\frac{1}{2}$ feet deep, and was thrown up to form a raised bank along the central axis of the alignment. On the south side the canal excavation through the high ground near Roorkee furnished material for the first portion of the aqueduct embankment which was pushed forward, and carried out into the valley by ordinary basket-labour, and by means of wheel-barrows working on continuous lines of planks. It soon, however, became necessary to lay down a tramway of light rails, and to employ large numbers of tip-wagons. At first the tip-wagons were propelled by manual labour, but as time went on horses in great measure took the place of men. Eventually, on the 22d December 1851, a steam locomotive was got to work to haul trains of earth or 'ballast' wagons across the whole extent of the valley. This engine, which was named the 'Thomason,' is interesting as being almost certainly the very first locomotive engine used for constructional purposes in India.

It was a small but compact machine, with both engine and tender on one frame, and it was supposed to be able to draw a maximum load of 200 tons on the level at four miles an hour. The engine, however, did not turn out a success; meeting with a bad accident it was discarded at the end of a few months' use. Shortly afterwards it was dismounted and utilised for driving machinery in the workshops at Roorkee. Inexperience in management—perhaps a little prejudice against it—and the want of proper facilities for expeditiously carrying out repairs, were no doubt the chief causes of the failure.

The double pair of walls in the embankment were built up to the level of the canal-bed gradually in proportion as the earthwork advanced in height. The line of rails occupied a bank raised along the central axis of the work, and at intervals of every 200 feet cross banks of earth were extended laterally, right and left, to the revetment walls. These cross banks served a double purpose, viz., as a passage for carrying earth for the embankments outside, or to the rear, of the masonry walls, and also for forming a series of rectangular hollow spaces, each about 200 feet long, between the central line of rails and the side walls, which acted as reservoirs or ponds for receiving and holding water during the rains, thus ensuring a good compression and consolidation of the earthwork in that part of

the embankment immediately below the canal bed, where it was most desirable.

Outside the revetment masonry, the earthwork above the level of the canal bed was completed by tip-wagons running on lines of rails carried along these portions of the bank. The earthwork filling between the double walls was brought up to the height necessary to serve as a centering on which the arch-work connecting them was constructed, this done, the masonry steps forming the visible revetment along the sides of the canal were finished off. At each end of the aqueduct embankments, the masonry revetment walls and earthworks terminate on the high ground at the edge of the valley, in contact with masonry bridges and structures built across the canal.

The Solani aqueduct embankments north and south of the river, over $2\frac{1}{2}$ miles in combined length, contain approximately about five million cubic feet, or nearly 200,000 cubic yards of brick masonry, and 59 millions of cubic feet, or nearly $2\frac{1}{4}$ million cubic yards of earthwork,—a mass of material that, piled together, would form a pyramid about 700 feet square on the base, and 400 feet in perpendicular height.

The Solani River itself is crossed by a masonry bridge 1110 feet in clear length. The open waterway is 750 feet long, composed of 15 arched openings each of 50 feet span. The *width* of the arches from face to face is no less than 192 feet, and their thickness at the crown is 4 feet 6 inches. They are segmental in form, with a rise of 8 feet in the centre. The piers are 10 feet thick at the springing of the archwork, and $12\frac{1}{2}$ feet in height. Above the arches the parapet or side walls of the aqueduct are 8 feet thick and 12 feet high above the canal bottom. Between these parapets the water flows with a width of 172 feet, and a full depth of 10 feet, but the complete width is divided into two channels, each 82 feet wide, by a longitudinal partition-wall along the centre. At each end of the partition-wall cross piers are built, fitted with grooves, corresponding with similar grooves in the side parapet-walls, into which planks can be inserted, so that either half of the aqueduct longitudinally can be closed and cleared of water whenever necessary for carrying out repairs. The water in the closed half is got rid of by discharging it into the Solani River

through sluices and passages in the aqueduct abutments provided for the purpose.

As seen from above the four corners of the structure are terminated by rusticated wing-walls, surmounted by pedestals, each carrying a recumbent lion, constructed of masonry and stuccoed. The lions face inwards towards the river, seeming to guard the portal by which the Solani is permitted to pass through the works. Other lions facing outwards are placed at the extreme ends of the masonry-protected approaches.

The piers and abutments of the main aqueduct are founded on blocks of brick masonry, sunk 20 feet deep into the river bed, which consists of sand intermixed with clay. The blocks are each 20 feet square, and are therefore cubes of brickwork of 20 feet a side. They are each pierced with four rectangular (or octagonal) openings or 'wells' through which the river-bed material was withdrawn during the process of sinking. Other blocks of varying dimensions support the 'cutwaters' or projecting portion of the piers, and the wing-walls and defences of the abutments. When the blocks were sunk to their full depth the well-openings were filled in and arched over at the top, so as to form a level platform on which the piers or abutments were built up.

The total width of the foundation works of the Solani aqueduct is 252 feet, and the quantity of masonry sunk out of sight below the river bed is probably not far from that visible above it. The construction of the archwork was commenced on the 1st December 1851, and the last arch was keyed in on the 4th July 1853. As we have stated, the total width of the archwork is 192 feet, but in order to lessen as far as possible the liability to distortion from any unequal settlement of so wide a mass of masonry, and for purposes of economy in centering, and general convenience, the archwork was constructed from shore to shore, in two half-widths, each of 96 feet. This series of up and down stream arches lie quite close to each other, but are not actually in contact. The construction of the whole magnificent work was practically completed by the end of March 1854.

In addition to the fine works above specially referred to, the

Ganges Canal in its short passage of about 20 miles across the low-valley land of the sacred river, admits into its bed five other smaller torrents, controlling these uncivilised and turbulent kinsfolk by means of suitable masonry works. The width of water-passage for these torrents is in two cases 150 and 100 feet respectively, in two cases 50 feet, and in one case 30 feet. At Roorkee the canal gains the high land of the Ganges-Jumna Doab, and continues its course free from the immense obstructions encountered in its first section. The main canal lies along the centre of the table-land between the Ganges and the Jumna, throwing off several main branches along the ridges between the intermediate smaller rivers, all adapted for internal navigation, as well as for irrigation. Irrigation commences just beyond Roorkee, at a little over 20 miles from the head-works.

Water was admitted into the canal by Lord Dalhousie on on the 8th April 1854. It is said that before the opening of the canal a considerable body of the Hindu priests, attached to the numerous temples situated along the bank of the river in front of the town of Hardwar, steadily refused to believe that the water of the Holy Ganges would ever consent to enter the canal, and so confident were they in this opinion that they formed themselves into a solid phalanx in the bed of the canal, just below the intake of the water, so that when the sluices were opened they might from this apparently dangerous position, duly emphasise before the assembled people the great miracle that would take place. As however the Ganges water proved amenable to the laws of gravity, the canal bed was expeditiously abandoned very soon after the gates were opened. This story may have some slight basis of fact, but is probably in the main apocryphal. The enormous benefit conferred on the community by the Ganges Canal is illustrated by the statement that probably as many lives were saved by it in Bengal during the year 1865-66 as perished during the same terrible year in Orissa. From statistics showing the amount of grain carried down country from the canal districts by the East Indian Railway, and by river transport, it is estimated that the canal in that year fed little short of 2½ millions of people. In the same year it repaid to the country more than its then total cost.

Subsequent experience showed that the slope allowed to the bed of the Ganges Canal was too great to allow, without dangerous erosion, the passage of the full volume of water originally contemplated, and some considerable remodelling was necessitated, which has proved successful in removing the main evils.

CHAPTER V

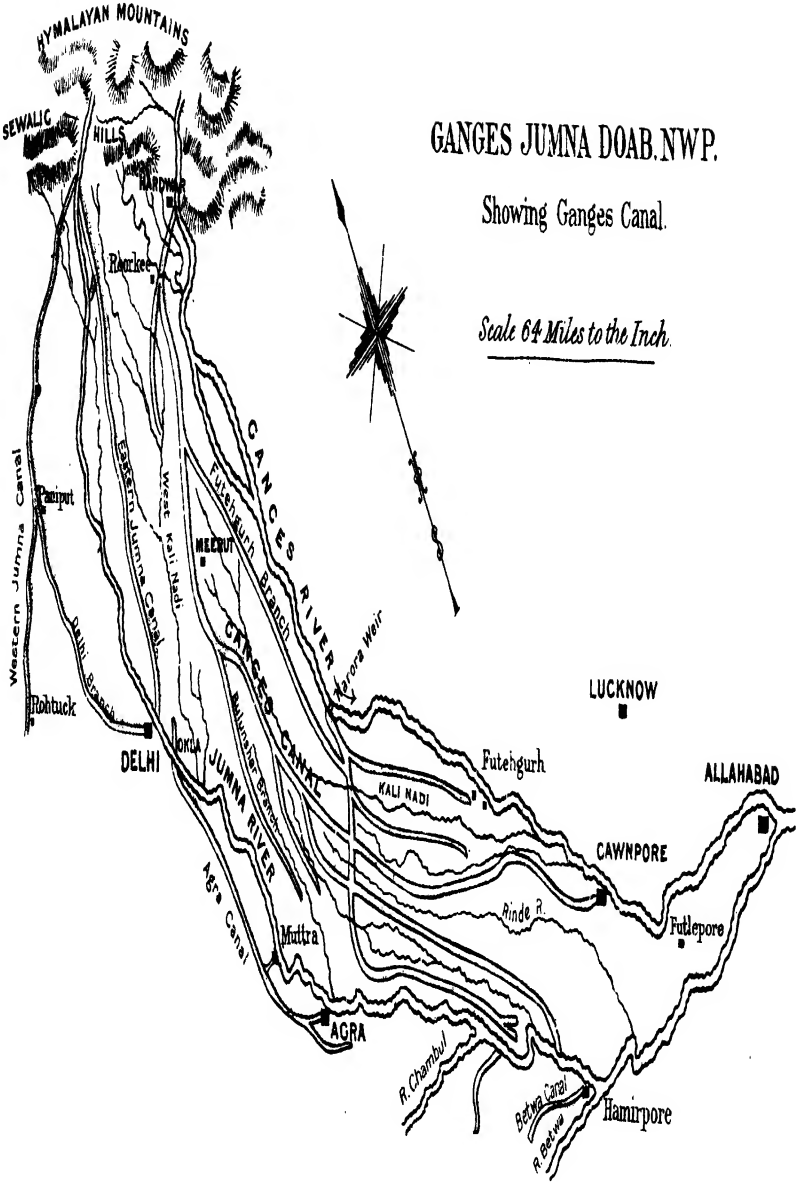
NORTH-WEST PROVINCES

Lower Ganges Canal: outline of newer system—Description and details of weir at Narora—Original Nadrai aqueduct—Partial destruction by floods—The new Nadrai aqueduct—Details of the structure—Foundation arches and general construction—Agra Canal—General course followed—Description of head works at Okla—First example of a weir in India crossing a river bed of fine sand of unknown depth—Betwa Canal—Origin of project—Particulars of head weir—Minor canals in the North-west Provinces—The Dun canals—The Rohilkund and Bignor canals—General results of irrigation in the North-west Provinces.

Lower Ganges Canal.

THE Ganges Canal as originally constructed was fully able to supply the wants of the upper portion of the Ganges-Jumna Doab, but lower down there remained large districts over which its influence did not, and could not, extend. This consideration led to the projection and subsequent construction of a lower system of canals derived from the Ganges, from above a weir which has been constructed at Narora, a place situated a few miles below Rajghat, where the Oudh and Rohilkund Railway crosses the river. In order to apportion a better distribution of the available water between the upper and lower halves of the Doab, various additions and extensions of the main branches and distributaries of the original work were incorporated in the new scheme.

The whole system of irrigation in the Ganges-Jumna Doab has for purposes of administrative convenience of late years been divided between what are now called the 'Upper' and 'Lower' Ganges Canals, the lower portions of Sir Proby Cautley's original work forming a part of the latter. The lines of main canal and principal branches of the whole combined system are exhibited on the accompanying map, and it will be convenient to consider the details of the upper and lower canals separately,



J. C. Drummond & Co., Lith. 14, Henrietta St, Covent Garden, W.C.

as they are now officially divided. The Upper Ganges Canal has a length of main line and branches of 456 miles, of which 213 miles are navigable, with upwards of 2500 miles of distributing channels. The maximum discharge of water by the canal is 6799 cubic feet per second, and it commands an irrigable area of 1,600,000 acres, irrigating in favourable years about 1,500,000 acres, or 2344 square miles.

The Lower Ganges Canal system, fed from the Ganges River at Narora, has a total length of main line and branches of 557 miles (including about 300 miles of what originally formed part of the old Ganges canal), with over 2000 miles of distributing channels. It commands an irrigable area of 1,187,326 acres, or 1855 square miles, but the system has not yet developed anything like its full working capacity, actually irrigating somewhat less than half of this area. The weir across the Ganges at Narora, with the adjoining scouring sluices, canal head, and navigation channel with lock, forms one of the finest and most imposing engineering constructions in India. It was begun in the year 1873, and was completed in 1878. This splendid weir, including the scouring-sluices in prolongation, is 4244 feet in length, or considerably over three quarters of a mile. At the point where the weir is constructed, the bed of the river consists of a very fine smooth sand, which, when wet, is almost fluid. Into this sand a long line of hollow blocks or wells, each 10 feet square, was sunk, down to a depth of about 30 feet for a distance of 500 feet from the scouring-sluices, which immediately adjoin the canal head, and to a depth of about 10 feet for the remaining part of the length of the weir. When sunk to the required depth the hollows in the blocks were filled in solid with concrete, and on this block foundation the main weir-wall was constructed, consisting of a wall of masonry 9 feet 9 inches high, and 8 feet thick, extending for a length of 3800 feet. Owing to the difficulty and expense of obtaining stone, the work has been constructed as an 'overfall' weir; there is, therefore, on the lower side, a floor 40 feet wide and 5 feet thick to receive the water falling over the weir-wall, and along the lower edge of this floor a line of circular wells, each 8 feet in diameter, is sunk to a depth of 20 feet below low water. To prevent the escape of the fine sand between these wells, the

small spaces between them are filled in by piles driven as closely together as possible. For a long distance on the down-stream side of the floor, an apron or slope of large heavy blocks is thrown to protect the river-bed from the action of the water. The weir is designed to raise the old cold-weather level of the water 7 feet, and in order to prevent a heavy deposit of sand taking place above the weir, which would inevitably block up the entrance to the canal, a line of scouring-sluices 444 feet in length, consisting of forty-two openings, each of 7 feet 3 inches clear width, is constructed on the side adjoining the canal head, in continuation of the weir proper. The scouring-sluices superstructure forms a handsome double-storied building, and stands on a stone and concrete flooring 5 feet thick, 427 feet long, and 155 feet wide, the whole being enclosed and supported by foundation blocks or 'wells,' 10 feet square and 12 feet deep.

At an angle with the line of the weir, the entrance of water into the canal is controlled by a regulating bridge having thirty sluice-openings, each 7 feet wide; and to admit the entrance and exit of boats, a navigable channel, having a lock 150 feet long and 20 feet wide, has been provided at a short distance above the regulator. About 32 miles from the headworks the main channel crosses the Kali Nadi at Nadrai by a splendid masonry aqueduct.

The existing Nadrai aqueduct is a recent structure, having been commenced in the year 1885, and completed in October 1889, in replacement of an older work which was destroyed by heavy floods occurring in the years 1884 and 1885. As it is the latest, so it is also one of the finest of the many remarkable canal aqueducts to be found in India.

During the construction of the main Lower Ganges Canal, the original Nadrai aqueduct across the Kali Nadi, or River, was built in the years 1874-76. The river above the site of the work was said to receive the drainage of over 2500 square miles. Owing, however, to its reception of spill-water from Ganges floods, the data for estimating its true maximum discharge was somewhat uncertain. The original aqueduct consisted of five arched spans of 35 feet by 14 feet, providing 2450 square feet of waterway, and for an estimated discharge of about 18,000 cubic feet per second. The piers and abutments were

founded on wells sunk in sand to a depth of 18 to 20 feet below the bed of the river. The canal passed over the aqueduct in a channel 192 feet wide and 9 feet deep, with a water velocity of 3 feet a second. On the 2d October 1884, this less than ten-year-old aqueduct was partially destroyed by a very heavy flood in the Kali, which undermined the foundations and carried away about a fourth of the structure. On the 17th July of the following year a still heavier flood occurred, which completed the destruction of the aqueduct, and it became necessary to design and commence the erection of an entirely new work with a greatly increased waterway.

About half-a-mile below the site of the work was an old native road-bridge, said to have been built more than a century ago, having a waterway consisting of seven openings of 10 feet 6 inches by 14½ feet, and two side openings of 8 by 5 feet, giving a total water area of 1146 square feet only—or less than one-half that of the canal aqueduct. This old native bridge—the existence of which had been supposed to justify to some extent the waterway allowed in the case of the original Nadrai aqueduct, was in no way injured by the floods which destroyed the latter. It happened—as had no doubt happened many times before—that the earth approach-banks on either side were washed away for the length of perhaps half-a-mile, giving an ample passage for the water, and leaving the bridge itself—not exactly high and dry—but isolated, as an island, in the middle of the current. It is in this way that many of these old native bridges of small dimensions find relief, and are saved from destruction in the highest floods, whilst the massive and substantial approach embankments of a canal aqueduct, or of a lofty railway bridge, confine the flood waters to the particular open waterway assigned, so that if this waterway happens to be insufficient the bridge is either undermined or overwhelmed.

After the partial destruction of the aqueduct in 1884, and its complete destruction in 1885, fresh investigations and calculations were made to ascertain the true maximum discharge of the river, and it was eventually determined to allow in the new structure an area of waterway more than four times greater than in the old one destroyed.

The new Nadrai aqueduct over the Kali river, the architec-

tural features of which are illustrated by the accompanying engraving, is constructed of brickwork, and is 1220 feet long over all, consisting of fifteen segmental arch openings of 60 feet each, carrying the canal, 130 feet wide and 7 feet deep at full water, at an elevation of 24 feet 3 inches above the bed of the river. On one side it carries a roadway, 10 feet, and on the other a bridle path, 5 feet in width. The breadth of the structure from face to face of the arches is 148¾ feet; the extreme width from nose to nose of the piers being 181 feet. The thickness of the arches at the crown is 3 feet 9 inches. The piers are 10 feet thick at the springing of the arches, 12 feet at at the bottom and 11¾ feet high above the river bed.

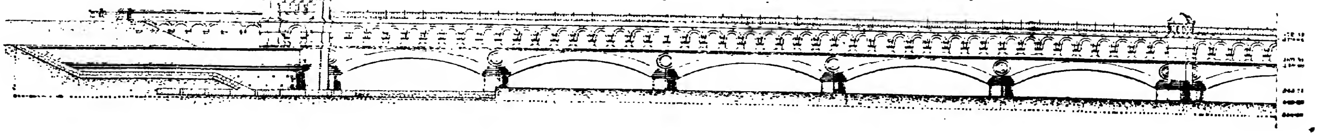
For purposes of economy and convenience the fifteen arches are divided into three bays or groups of five arches each, by two abutment piers, which are twenty feet thick at the top.

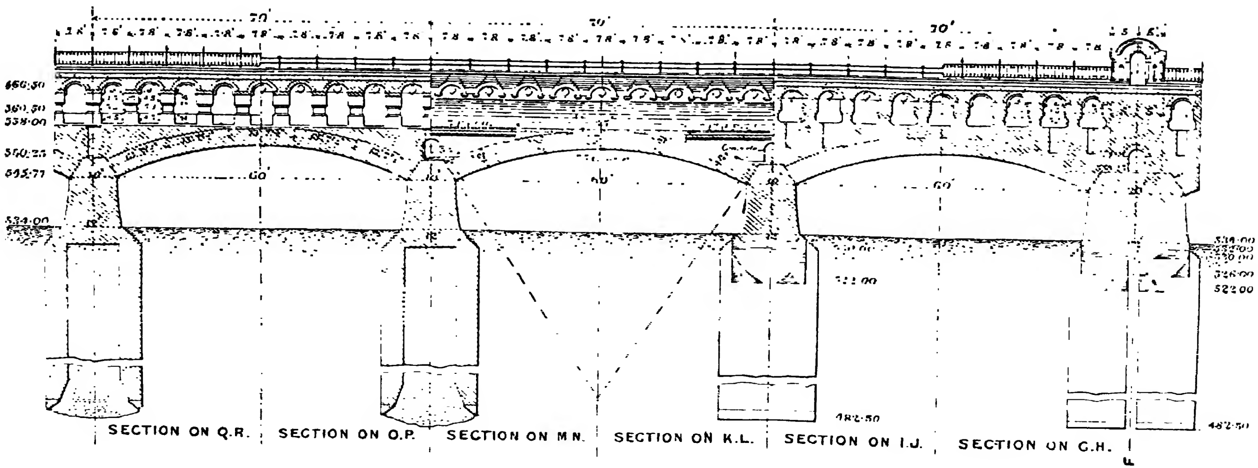
The aqueduct superstructure is founded on circular wells, those under each ordinary pier consisting of a single row of eight wells, each 20 feet in external, and 11 feet in internal, diameter. The abutment piers and shore abutments are founded on double rows of wells of 13, and 12 feet external, and 6 feet 3 inches internal diameter. These wells were sunk from 45 to 50 feet into the river bed; the first 25 feet or more being sunk through sand, and the remainder through a hard, tenacious clay. When pushed down to the full depth the wells were filled in with concrete, and the tops were overlaid with a solid masonry platform 4 feet in thickness, to form the base of the superstructure. The number of wells sunk was 268, and their united length was 15,019 feet, or nearly three miles of brick well-work.

Owing to the great breadth of the aqueduct, the arches were turned in three, and latterly in two, sections, each one-third or one-half of the total width of the archwork. The line of separation between the sections was, after the arches were completed and had finally settled into position, covered by arch rings of brickwork, 5 feet wide and 15 inches thick, let into the upper surface of the archwork.

The main arches cover an area of over three acres, and weigh over 30,000 tons. The centering on which this immense mass of arch masonry was constructed, 75 feet in width and 60 feet

Fig 1 NADRAI NEW AQUEDUCT.





long, were moved bodily on wheels and tram-roads, from section to section, or from arch-group to arch-group. By this means a very great saving in time was effected, with the result that the arches were built in 176 days, or at the average rate of less than twelve days per arch, out of which twenty-five days only were occupied in moving the centerings. Upwards of fifty-eight millions of bricks were used in the construction of the aqueduct, and the total cost of the work, including subsidiary operations, amounted to about £360,000, or thirty-six lacs of rupees.[1]

Another of the principal canals of the North-west Provinces is the 'Agra Canal,' taken from the right bank of the river Jumna at Okla, about eight miles below Delhi. The Eastern and Western Jumna Canals, situated higher up the river, draw off the whole of the water from the Jumna in the dry season, leaving the bed quite empty; nevertheless, by the time the river has reached Delhi underground filtration and intermediate drainage has furnished a fresh supply, amounting to an average of about 700 cubic feet per second during the hot weather. At first it was contemplated to utilise this water in the Ganges Jumna Doab, to supplement the irrigation in the Ganges Canal districts, but eventually it was decided to construct a large canal on the right bank of the river to irrigate a very dry and parched tract of country lying between Delhi and Agra. **Agra Canal.**

As it was designed to draw off the whole of the water in the river Jumna at Okla during the dry season, the bed of the river between Delhi and Agra would be left practically dry, all navigation by the natural stream being of course stopped. The Agra Canal, therefore, has been made navigable throughout, so that boats quitting the Jumna at Delhi proceed by the canal, and rejoin the river through a navigable channel and lock at Agra. A navigable branch also connects the main canal with the populous city of Muttra, and an extension of the Delhi branch of the Western Jumna Canal, to link it with the Agra Canal, was also designed. Through this link, when the Punjab

[1] The data in this description is abbreviated from a paper on the construction of the new Nadrai Aqueduct, by Mr. W. Good. Vol. cv. *Proceedings of Institution of Civil Engineers.*

system of canals is completed, inland navigation will extend through the watershed separating the Ganges and Indus basins, so that boats will be able to traverse the whole length of country from the mouths of the Ganges to the mouths of the Indus.

The Agra Canal was opened in the year 1874. It has a total length of main line and branches and navigable channels of 134 miles, with nearly 600 miles of distributaries, commanding an irrigable area of 240,000 acres, or 375 square miles. The head of the canal is situated just above the weir thrown across the bed of the Jumna at Okla. This weir was the first made in India in a river bed consisting of fine semi-fluid sand. It consists of two parallel masonry walls 26 feet apart and 2428 feet long, laid on the river bed itself, without any sunk foundation. The space between the walls is filled in with large blocks of stone, well packed. On the up-stream side of the front wall a heavy protection of loose stone, 40 feet or more in width, and having a slope of 1 foot in every 4, is carried from the river bed to the crest of the wall. On the down-stream side of the rear-wall there is a wide apron formed of heavy stone, no less than 180 feet in width, with an easy slope of 1 foot in every 20 feet. The total width of the weir, therefore, over all is more than 250 feet, and the main weir walls are so encased and protected by masses of packed stone on either hand as to be quite beyond the reach of any scouring action of the water.

The front wall is 8 feet thick at the bottom, where it rests on the sandy bed of the river, and 4 feet thick at the top, which is placed at 7 feet above the lowest water-level. The rear wall is somewhat smaller. The rise of the river in times of high floods is about 11 feet, and at such times the obstruction presented by the weir causes a fall in the surface of the water of between 3 and 4 feet. There is, consequently, a very severe action on the down-stream apron of packed stone, which, soon after the weir was first made, did a good deal of damage, necessitating the subsequent breaking up of the rear slope, and binding it together by additional longitudinal walls carried through it. On the side of the river, where the canal head is situated, there is a set of scouring sluices, to prevent

the accumulation of sand above; and an embankment is carried along the river bank for about eight miles to protect the adjoining lands from inundation, and to prevent the water wearing its way round the end of the weir. From its regulating bridge at Okla the canal follows a course nearly parallel with the Jumna, and at no point very far from it. The tail end of the canal is led into the river Utongou, about twenty miles below Agra.

So far back as the year 1855 a scheme was proposed by Captain (afterwards Major-General) Strachey for a canal to be drawn from the left bank of the river Betwa near Paricha, a point about thirteen miles east of Jhansi, to irrigate the tract of country lying in the angle between the Betwa and the Jumna, in the centre of which is the town of Jalaun, and a party sometime afterwards appointed to investigate the subject perished during the Mutiny. Nothing was done until the years 1867 to 1869, when a detailed project and estimates were prepared, which, however, fell to the ground, and the scheme was in abeyance until 1872-73, when further studies and estimates were made. A matured project was finally sanctioned as a famine 'protective' work in 1881, and the existing Betwa Canal was opened in the year 1885. **Betwa Canal**

A fine masonry weir was constructed across the Betwa at a point where the river is crossed by several rocky barriers. The weir, which is of serpentine form, taking in an island and a reef of rocks in its passage, is 4246 feet long, including the island, and 4000 feet of clear construction. In height, owing to the irregularity of the river bed, it varies from 3 feet up to 60 feet in the deepest channel. At right angles to, and adjoining the canal head, a set of four under sluices with a training wall, stands in front of the canal mouth. The regulating bridge across the entrance to the canal has five openings of 6 feet each, provided with sluice gates, and divided by piers 4 feet thick. The canal starts with a bottom width of 25 feet, and at a little over twenty miles from the head it divides into two main branches, one extending to the Jumna near Hamirpur, and the other tailing into the same river higher up, near Kathaund. From the Hamirpur branch a secondary branch runs to Kalpi.

The canal has a mileage of main line and branches of 168 miles, with over 300 miles of distributing channels, command-

ing about 150,000 acres, but hitherto irrigating only a comparatively small portion of this area. Incorporated with the Betwa canal a small amount of irrigation is carried on from the Jhansi and Hamirpur lakes through about 70 miles of distributaries, irrigating about 2000 acres.

Minor Canals.

The remaining minor canals in the North-west Provinces are the 'Dun Canals,' the 'Rohilkund Canals,' and the 'Bignor Canals.' The Dun Canals are situated to the north of the Sewalik range, between the Jumna and the Ganges. There are five principal channels, having a total length of 74 miles, and irrigating from 20,000 to 25,000 acres. The Rohilkund Canals are a group of small irrigation channels situated in the Bareilly district between the Ramgunga and Sarda rivers. They consist of 20 miles of main canal, with 337 miles of distributaries, irrigating about 95,000 acres. The Bignor Canals are a much smaller group in the Moradabad district, having about 38 miles of channels, and irrigating about 9000 acres.

General results North-west Provinces Canals.

In the whole North-west Provinces, up to the year 1889-90, there have been constructed by the British Government 1465 miles of main canal and branches, of which 535 miles are navigable, disseminating the fertilising influence of water through 6646 miles of distributing channels, and irrigating two millions of acres, or 3125 square miles. The capital cost of these works amounted to £8,059,300. In the year mentioned above the total net direct and indirect revenue derived from the whole of the provincial canals amounted to £370,563, or 4·58 per cent. on the capital expended.

The accumulated surplus, after deducting interest charges, amounts to £689,615, or over 8½ per cent. on the capital cost of the works, due, however, to the Eastern Jumna Canal, which, taken alone, exhibits a clear accumulated net revenue of £1,357,699. The total value of the crops irrigated by the North-west Province Canals in the year 1889-90 amounted to no less than £6,527,234.[1]

[1] For details of individual works in the North-west Provinces *vide* Appendix B.

CHAPTER VI

BENGAL AND CENTRAL INDIA

Bengal Canals—New conditions of rainfall, and peculiarities—Outline of Bengal Canal system—Orissa Canals—Delta Canals and formation of Delta lands—East India Irrigation Company—Description of Orissa Canal system—Head works and weirs at and near Cuttack—Midnapore Canal—General course and particulars—Sone Canals—Largest scheme in Bengal—Early history—Description of Sone Canals—Details of weir at Dehree—Construction—Hidgellee Tidal Canal—Orissa Coast Canal—Particulars of works—Calcutta and Eastern Canals—Sarun Canal—Eden and Madhuban Canals—General results of irrigation in Bengal—Central districts of India—Colonel Dixon and Rajputana tanks.

PROCEEDING now to a consideration of the various irrigation and other canals constructed by the British Government in the province of Bengal, we find ourselves at the outset confronted with an entirely new set of circumstances and conditions. As we proceed eastwards from the irrigated districts of the North-west Provinces, and follow the Ganges river towards its delta at the head of the Bay of Bengal, we find the average annual rainfall gradually increasing, and the absolute necessity for irrigation becoming less and less, until, on reaching the extreme eastern side of the province, the rainfall is so large and invariable that any failure of the crops from scarcity of water is a contingency hitherto unknown. Bengal Canals.

In Behar, on the western side of the province, artificial irrigation of the soil from numerous wells, small surface tanks, or inundation canals, has for ages been commonly practised, more especially for the extensively grown winter crops, which cannot be efficiently cultivated without a regular supply of water. Farther to the south and south-east an increasing rainfall and a general prevalence of wet-season cultivation, causes artificial irrigation to be more and more a means of improvement, of enhancement of the out-turn, and an insurance against

bad years, than an absolute necessity: hence its introduction has been slow and difficult, being against the conservative tendencies of the cultivators, who have been, and still are, to a great extent apathetic, or even actively opposed, to the introduction of artificial irrigation—or rather to payment for the use of canal water. In the district of Orissa, bordering the sea, the rainfall is usually large and ample for the rice crops which are mostly grown, but sometimes, at long intervals, a total failure of the monsoon occurs, and from the formerly isolated position of the district such times have been attended with the most disastrous consequences, as in the terrible famine of 1866.

In this part of Bengal, as elsewhere over a great part of the province, although the out-turn of the rice fields is greatly enhanced by the systematic and regular employment of an unfailing water supply—and is absolutely dependent on it in bad seasons, the expense of canal water, even at the lowest rates, is sufficient to create in the minds of the peasants a strong disinclination to use it, and a disposition to trust entirely to the ordinary chances of the annual rainfall. On the eve of the famine year 1866 a new assessment of the land-tax was impending in Orissa, and a popular saying of the peasants is quoted, which at the time became famous, as follows: 'It is better that one or two of us in each family should die of famine, than that by using irrigation for our land we should give the government an excuse for raising the tax on ourselves and our children for generations.' Of late years, however, some of this prejudice, and absence of intelligent foresight, has been slowly overcome, although much remains to be done before a knowledge of the full benefits and advantages, insured by an unfailing water-supply for purposes of cultivation, is likely to be at all widely diffused in Bengal.

From the above and other causes, amongst which to the circumstance that most of the large irrigation projects, as carried out in the Bengal Province, are truncated and contracted portions of larger schemes, each provided with initial main works capable of dealing with a far greater quantity of water than has hitherto been actually used, and consequently much more costly works than if they had been originally devised to irrigate only the smaller area, the financial working of

the Bengal irrigation canals has not as yet been a success. There appears, however, little reason to doubt that in course of time, as the demand for water increases, and the maximum number of distributaries capable of being fed from the main channels are called for and constructed, the canals may become commercially remunerative.

In the Province of Bengal there are three canal systems of large size and importance, all of which combine navigation with irrigation. These are the 'Orissa Canals,' the 'Midnapur Canals,' and the 'Sone Canals.' In addition to these there are three canals, which are entirely for navigation purposes, viz., the 'Hidgellee Tidal Canal,' the 'Orissa Coast Canal' in continuation, and the 'Calcutta and Eastern Canals.' There are also three small systems, viz., the 'Sarun,' the 'Eden,' and the 'Madhuban' canals, mostly used for irrigation purposes, and the 'Nuddea rivers system,' the works on which are designed for the improvement and maintenance of the river channels, and to secure a continuous supply of water from the Ganges to the Hoogly to facilitate navigation.

Orissa Canal.

The 'Orissa' system of canals irrigate large tracts in the deltas of the Mahanadi and Brahmani rivers. The term *Delta* is usually applied to that fan-shaped area of country which lies between the two main branches of the series of channels, into which large rivers break up on entering the sea. This tract of country is generally formed somewhat like the Greek letter 'delta' (Δ), hence the name given to it. The term, however, strictly includes all the land at the river-mouth formed by overflow deposit from the river itself.

The formation of a delta is a continued process of land formation, incessantly going on at the mouth of every large river bringing down great quantities of matter held in suspension in its water. If we could accurately measure the precise quantity of solid material so brought down every year by any river, we should be able to measure the exact rate of the growth of its 'delta.' As soon as the river joins the sea, the 'silt' or solid matter brought down by its flood water is slowly deposited. In process of time a spur of land is built up, which gradually rises higher and higher. The velocity of the water becomes more and more checked, and the deposit during the highest

floods slowly builds up the adjoining land, and forms banks which are only occasionally topped by the river, which, so long as it continues confined to its channel, carries much of its solid material farther and farther out into the sea, lengthening the spur of new land. Presently the discharge outlet of the river becomes so impeded by the raised level in its front that during some extra high flood the banks are burst, and a new channel or channels are scoured out in the newly-made ground. Such channel or channels, which soon become important river branches, take the most direct and shortest road to the sea. As time goes on, the process repeats itself in the new branches themselves, and other channels are then successively scoured out, each in its turn building up new land in its vicinity, which thus becomes spread out into a fan-shaped prominence. The whole delta continues to extend itself farther and farther into the sea at a slowly diminishing rate, until the wearing away and transporting action of some oceanic current may balance the amount of deposit brought down by the river.

The irrigation of the Mahanadi and Brahmani deltas was first suggested about the year 1858 by Colonel (afterwards Sir Authur) Cotton, who drew up a scheme intended to irrigate about $2\frac{1}{4}$ million acres, and comprised 530 miles of navigation channels. In the year 1861 a company called the 'East India Irrigation Company' was formed, which, under contract with the Government, undertook to execute in the Deltas extensive works for irrigation, the opening out of communications, and the protection of the country from the severe floods to which it was peculiarly liable. In this district, which is almost a level plain, the average annual rainfall is as high as 57 inches; but the cultivation consists almost entirely of wet-season crops, consequently any failure or early cessation of the rains leads to inevitable disaster, and the main object of the works which were intrusted to the Company was to ensure a large area of country against recurring risk of famine.

The works were commenced in 1863; but the progress and development of the scheme proving unsatisfactory, in the year 1868 the Company was bought out by the Government, and the whole project was revised and re-estimated. Under the scheme as actually initiated, the Orissa canals were intended to

irrigate 1,147,000 acres; but the project was eventually so curtailed that the works as now completed and contemplated, command an area of but little over 500,000 acres. The Orissa canal system—unlike the greater part of those systems which we have lately described in the Punjab and North-west Provinces—does not consist of a single main canal, giving off numerous lateral branches, but consists of several detached canals, derived from the Mahanadi or its offshoots, at the head of the Delta, from which point, as from a centre, they radiate, and spread out like the ribs of a fan, following a general course parallel to the Delta streams.

The head works of the system, which consists of several weirs and canal heads, lie at, and about, Cuttack, at a short distance below the point where the Mahanadi issues from the line of hills along the coast. The weirs near Cuttack are three in number. The first is situated a few miles above the town, at Naraje, and is thrown across the 'Katjooree' river, close to the point where this branch bifurcates, and leads off from the right bank of the Mahanadi. The Naraje weir is 3600 feet long, and 12 feet high above the river bed. During high floods, 15 to 18 feet in depth of water passes over the summit or 'crest' of the weir wall. Near the right bank a set of sluices supplies a channel conveying water to the town of Cuttack. The weir has no canal head above it, its object being merely to regulate the quantity of water allowed to pass down the 'Katjooree,' or the main Mahanadi channel, respectively. The vertical masonry wall, 12 feet high, forming the weir, is protected on the up-stream side by rough blocks of stone forming a slope of about 2 to 1. On the down-stream side, there is an apron of rough stone, varying from 120 to 300 feet wide, composed of very large stones, each about two tons in weight. The slope is broken up by two masonry walls running parallel to the main weir wall, and by numerous cross walls running at right angles to the same, thus dividing the apron into a series of rectangular compartments, into which the rough stone is carefully packed.

The second weir is across the Mahanadi itself at Cuttack. It is 6349 feet, or about 1¼ miles long, and 12 feet in height above the low-water level of the river, which rises over 20 feet

in high floods. The weir is formed of three vertical and parallel walls, founded on circular wells 6 feet in diameter, sunk 6 feet into the river bed. The space between the walls is filled in with rough stone, finished off at the top with blocks of stone of large size, set on edge, with an inclination towards the current. In the centre of the weir a set of scouring-sluices is provided, having wide bays or openings, 50 feet in width, fitted with folding-back gates or shutters, on the French system, nearly similar to those described further on in the case of the Sone weir. There is also a long set of 'under' or scouring sluices, on the right flank of the weir, adjoining the regulator of the 'Central Delta,' or 'Talundah' canal, which takes off at this point. The Talundah canal is 27 miles long, and not far from its head it gives off a main branch called the 'Machgong,' 32 miles in length.

The third weir is thrown across a second, and left branch of the Mahanadi, called the 'Beropa' river. This weir is 1980 feet long, and 9 feet high in the deepest part. In construction it is similar to that over the Mahanadi at Cuttack. From the pool above the Beropa weir, canals are taken off from both sides. It is therefore provided with two sets of scouring sluices, adjoining the canal heads. The canal drawn off from the right bank is the 'Kendrapurni' Canal, 55 miles long, giving off two main branches, viz., the 'Patamoondi,' 47 miles long; and the 'Gobree,' 21 miles long. The Kendrapurni channel runs parallel with the left bank of the main Mahanadi to Jumboo, on the sea coast. The second canal drawn off from the left flank of the Beropa weir is the 'High level canal,' 64½ miles long. This channel traverses the foot of the high ground from Cuttack to Bhuddruck, and forms a connection in its passage, between the Mahanadi, Brahmani, and Byturni rivers, obtaining from the two last-mentioned streams a supplementary supply of water by means of two secondary weirs thrown across them. A small independent canal 6½ miles long, called the 'Jajepore,' is also led off from above the Byturni weir.

The Orissa system of canals and distributaries is not yet fully completed. At the end of the year 1890-91 it had a total length of main and branch canals of 252 miles (of which 177 miles are

navigable), with 765 miles of distributing channels. In the same year it irrigated 189,299 acres. When the project is completed, as at present contemplated, it will have a total length of main canal and branches of 284 miles, with 2147 miles of distributaries, and will be capable of irrigating nearly 400,000 acres.

Midnapore Canal. The 'Midnapore Canal,' the first portion of which was opened in 1871, formed a portion of the original scheme for irrigation and navigation canals in Bengal, undertaken by the East India Irrigation Company, by which Company the works were commenced, but they were eventually finished by Government agency. The canal forms a navigable connection, through the Hooghly, between Midnapore and Calcutta. It is derived from the Cossye river, from above a weir which has been constructed at Midnapore. The total length is divided into four detached portions. The first length after a course of 25 miles again joins a lower reach of the Cossye at Panchkoora, where a second weir is built across the stream. After crossing the river through entrance and exit locks, the second length, 12 miles long, is locked into the Roopnarain river. Five miles lower down the Roopnarain channel, the canal again leaves it by a lock on the opposite bank, and the third length, after a short stretch of 4 miles, reaches the Damooda river, which it also enters and leaves by locks on either bank. The fourth length, 7 miles long, takes the canal to the Hooghly, which it enters by a lock at Ooloobería. From this point to Calcutta by the Hooghly channel the distance is 17 miles.

The Midnapore system of main and branch canals has a total length of 72 miles, all being navigable, and 339 miles of distributing channels. It commands an irrigable area of 180,000 acres, but actually irrigates from 80 to 100 thousand acres, according to the season; nearly the whole of the irrigated crop consisting of rice. A large portion of the revenue receipts from this canal is derived from the navigation, including the traffic worked by the steamers of the Calcutta Steam Navigation Company.

Sone Canals. By far the largest scheme for irrigation in the Bengal Province is the system of 'Sone Canals,' irrigating an extensive triangular tract of country lying south of the Ganges. The

northern base of the triangle extends from Patna on the east to Dildarnagar on the west, the apex lying at Dehree, on the Sone, about 25 miles from the point where that river issues from the Kymore range of hills, and close to the fine causeway on which the Grand Trunk road crosses the Sone river.

The first suggestion for the irrigation of the districts west of the Sone was made by Lieut. (now Major-General) C. H. Dickens, in the year 1853, who proposed to employ storage reservoirs situated in the hills to the south. This idea was, however, abandoned, and a project for utilising the waters of the Sone river was substituted. In 1862 an offer was made by the East India Irrigation Company to carry out the works, and a very large amplification of the original proposal, by means of which connections would be made with Allahabad on the west, and with the Hoogly on the east, was mooted, but the scheme was considered by the Government to be of too extensive a character. In 1864 an agreement was entered into with the company for the construction of a restricted system of irrigation and navigable canals, more in accordance with the original project, lying to the southward of Patna on the east, and of Chunar on the west. The company, however, failed to raise the necessary capital, and, after some negotiations, the project was taken over by the Government in 1868; the small expenditure of £14,000 incurred by the company in preliminary operations being refunded. In 1869 the works were commenced by the Government, but in 1871 it was decided to restrict the scope of the scheme to the limits as now actually carried out, principally owing to considerations connected with the seasonable supply of water to be derived from the Sone river. The Sone Canals, in outline, consist of the following works. A magnificent weir across the Sone at Dehree, fro above which two main canals are led off—one from each bank That on the east side, or the 'Main Eastern Canal,' is a short navigable connection, 7½ miles long only, from the Sone to the Poonpoon river. From about the middle of this length the 'Patna Branch Canal,' 79 miles long, and navigable throughout, issues, and is carried nearly parallel with the east bank of the Sone to the Ganges near Dinapore. This branch in its

course to the Ganges descends through thirteen locks, and irrigates by means of numerous minor channels the districts lying between the Sone and the Poonpoon rivers. The second canal taking off on the west flank of the weir, or the 'Main Western Canal,' is also of the short length of 21½ miles. At the fifth mile the 'Arrah' navigable branch, 65½ miles long, branches off, and runs with a fairly straight course to Arrah, terminating in the Gungi nala, which communicates with the Ganges. There are thirteen locks on this branch, with an aggregate fall of 161 feet. From its western bank two large irrigation branches issue, viz., the 'Dumaon' branch, 40¼ miles long, and the 'Behea' branch, 31 miles long. At the ninth mile the Main Western Canal crosses the Kao river by a large masonry aqueduct, and at the twelfth mile gives off the 'Buxar' navigable branch, 45½ miles long, extending to the Ganges at Buxar. On this branch there are twelve locks, with an aggregate fall of 154 feet. At the nineteenth mile the Main Western Canal gives off the 'Chowsa' irrigation branch, 39½ miles long, which tails into the Karummasa nala a few miles south of Dildarnagar station on the East India Railway.

The whole system of 'Sone Canals' consists of 367¼ miles of main and branch canals, of which 218½ miles are navigable, and 148¾ are exclusively for irrigation. There are also 1211 miles of distributing channels. The area commanded by the system is 1,728,509 acres. In the year 1884-85 the canals irrigated a maximum of 370,661 acres, but the average area irrigated for the ten years, 1881 to 1891, is 293,153 acres. Hitherto the Sone system has yielded no return on the capital, inclusive of interest, spent on its construction.

The site of the enormous weir across the Sone at Dehree is about 600 yards above the Grand Trunk Road causeway. It is the longest weir in one uninterrupted line of masonry that has yet been anywhere constructed, the total length between the abutments being 12,550 feet, or nearly 2½ miles, and its construction involved the carriage and building up of 750,000 tons of stone. At the point where the weir crosses the Sone the river has a clear continuous waterway, with no islands in mid-channel to contract the length of the artificial works. The banks on either side—which are high—are not overtopped

by the highest floods, and the bed of the river is composed of coarse sand and pebbles.

The weir consists of three parallel walls, 9 feet high, above the bed of the river, the spaces between the walls being filled in with rough stone, finished off at the top by a course of large sandstone blocks regularly laid. It is founded on a series of hollow rectangular blocks, or 'wells,' of rubble sandstone masonry, sunk to a depth of about 10 feet, and the hollows filled in with concrete. The blocks are 10 feet by 6 feet in outside dimensions, with walls 15 inches thick. To prevent them from splitting during the process of sinking—which was effected by the use of mechanical excavators taking out the river-bed material from the central hollow spaces—sets of blocks were tied together by an arrangement of iron rods, so contrived that as soon as the set was sunk the rods could be withdrawn and utilised for the next set. On the up-stream side of the front wall there is a protective slope of rough stone, having a slope of 2 to 1. On the down-stream side the weir 'apron,' about 100 feet wide, extends with a slope of 1 in 10. There are three sets of 'under' or scouring sluices in the body of the weir, each set 500 feet long; one in the centre of the river and one adjoining each bank, just below the head sluices of the two canals led off. These under sluices are constructed with openings, or bays, of 20 feet each, and the bays are opened or closed by two sets of folding-back shutters, or gates, the front set being fitted with hollow iron backstays, or struts, which act as hydraulic brakes. When the shutter-gates are down the hollow tube forming the backstay fills with water, but in moving the shutter, either up or down, the water is forced out of a small vent hole by a movable piston, or plunger. The resistance of the water, escaping only through the small hole, acts as a brake, and prevents the sudden shocks apt to be caused by the force of the current against the shutters whilst in motion. The depth of water passing over the Sone weir during the highest floods is 7 feet, with a maximum velocity of about 8 miles an hour.

Hidgellee Tidal Canal.

The 'Hidgellee Tidal Canal,' the 'Orissa Coast Canal,' and the 'Calcutta and Eastern Canals,' are navigation channels only. The first, having the Orissa coast canal in prolongation, com-

mences on the right bank of the Hooghly, just below the junction of the Roopnarain River, and the two canals together serve to connect the Hooghly with the water system of Orissa. The Hidgellee Tidal Canal is 29 miles long, divided into two lengths —one of 11 miles from the Hooghly to the Huldee River, which it crosses through locks on either bank—and the other of 18 miles from the Huldee to the Russulpore River, which it enters by a lock nearly opposite another, admitting entrance into the 'Orissa Coast Canal,' which latter thence extends for a distance of 97½ miles in a south-westerly direction through Balasore, keeping roughly parallel with the sea-coast.

The Orissa Coast Canal was fully opened in the year 1887-88. It is divided into three ranges or sections, by locks at the passages of two important rivers, viz., the 'Soobarnrekha' and the 'Burbullong;' the middle section, or that between these two rivers, being divided into two sub-sections by locks at the crossing of the 'Panchpara' River. The lengths of the three main sections are 36, 23½, and 38 miles respectively, the sub-sections in the middle range being 17 and 6½ miles. Orissa Coast Canal.

The works consist of the above-mentioned separate lengths of simple canal with level beds connecting the rivers named, provided with terminal locks at each extremity to retain in the canals the requisite depth of water required for the navigation. The bottom width of the canal varies from 46 to 50 feet, and the minimum depth of water retained is 7 feet. The canal embankments are carried to a height of 3 feet above the highest floods.

During the dry season the canal sections are fed by the tidal waters of the different rivers connected by them, and during the rainy season the drainage intercepted by the canals themselves is utilised. The navigation terminates on the left bank of the Metai River in Orissa (about 15 miles from Bhuddruck) in connection with the inland water system of the district.

The 'Calcutta and Eastern Navigation Canals' have an aggregate length of 47 miles, and serve to maintain communication between Calcutta and the Eastern districts of Bengal, through the numerous channels of the Sundarbands. Calcutta and Eastern Canals.

The 'Sarun Canal Scheme' is a small irrigation and drainage system on the Gundluck River, cuts from which supply water Sarun Canal

to numerous old channels which intersect the district. The distribution of the water is undertaken by the landholders and planters immediately concerned. The length of main line and branches is 19 miles only, in addition to which about 28 miles of supply channels are maintained. The system commands an area of 64,000 acres, the area actually irrigated being very much less than this, but varying greatly from year to year.

Eden and Madhuban Canals.

The 'Eden Canal' is a small work for flushing some of the streams in the Burdwan district with water from the Damooda River, chiefly to give a good supply of drinking water, and the 'Madhuban' Canal is a very small irrigation work in the Champarun district.

General results.

In the province of Bengal up to the end of the year 1890-91, there has been constructed under the British Government 710½ miles of main and branch canals for irrigation, and 173½ miles of canal for navigation purposes only, or a total length of 884 miles. The irrigation canals are provided with 2315 miles of distributaries, exclusive of numerous village channels. The area commanded is 2,483,781 acres, of which in the year 1890-91, 545,541 acres only were actually irrigated, but this area varies largely according to the rainfall of the year. The value of the irrigated crops in the same year was £1,665,481.

The capital cost of the Bengal canal systems was £7,200,196. None of the four large schemes classed as 'major works' have as yet given any return on the capital, inclusive of interest charges, and of the minor systems two only yield a small profit. The net deficit on the whole provincial system of canals in the year 1890-91 amounted to £224,449, and from the commencement, including interest on the capital, in the case of those works constructed with borrowed funds, the net deficit reached the sum of £2,754,253. The heavy cost of the Orissa and Sone systems, the high average rainfall, accompanied by the general prejudice against the use of canal water at anything like remunerative rates existing in the province, and the absence of any large irrigation works of long standing, such as exists in the Punjab and North-west Provinces, to balance the immediate loss on the newer works, has told with great severity against the comparative net commercial results of the Bengal canals, but when that length of time which nearly all irrigation works take

to fully develop has passed, these canals under careful and judicious management may yet arrive at the remunerative stage.[1]

Central districts of India.

Westwards of the great basin of the Mahanadi, across the line of tributaries to the Godavery and Nurbudda rivers, artificial irrigation is extensively practised on a small scale over considerable areas by means of surface tanks, but the country being for the most part broken up into more or less confined valleys, is destitute of large and important irrigation works. In the district of Nimar, acquired from the Peishwa in 1818, a storage tank 3 miles round, called the Lachma Lake—an old native work which was found to be in ruins, was soon afterwards restored, and over one hundred smaller tanks were put in working order. In the years 1845-46, Captain Ffrench, the political officer then in charge of Nimar, made a masonry dam across the Chuli ravine, and another large earthen dam across the Chapri, thus forming the considerable 'Chuli' and 'Mandleswar' tanks.[2]

Rajpootana Tanks.

In any account of the irrigation works of India it would be unpardonable to omit mention of the system of storage tanks in Rajpootana, in the districts of Ajmere and Mairwarra, initiated by Colonel Dixon in the year 1835-36. In the ten years, 1836 to 1846, upwards of 2000 tanks and over 9000 wells were constructed, irrigating 15,000 acres of cultivation. The soil of the districts, owing to its sandy nature, is unsuitable for earthen reservoir embankments. Colonel Dixon, therefore, largely employed masonry in his dams, in some cases supporting a wall of masonry by an earthen bank behind it, in others building the entire dams of stone. These works were carried out in the midst of a then notoriously turbulent population, which was by tact and energy led to agricultural pursuits, and gradually reduced to order and quiet. The unruly Mairs under the influence of the improvements effected, were rapidly converted into the peaceful and industrious peasantry which they have since remained.

Some of the tanks constructed by Colonel Dixon are of considerable size. The 'Kabra Tank' in Mairwarra has an embank-

[1] For details of individual works in Bengal, *vide* Appendix C.

[2] Parliamentary Paper, *vide* note, page 8.

ment faced with a heavy masonry wall 620 feet long, 27 feet wide at the base, and 10 feet thick at the top: the height from the foundation being 33 feet. Another reservoir in Ajmere has a dam 60 feet high, built entirely of stone, and many other works of scarcely inferior dimensions were constructed.

CHAPTER VII

MADRAS IRRIGATION

Madras canals—Delta irrigation schemes—Kaveri and Kalerun deltas—Distinguishing features of Madras irrigation—Rainfall—Varying conditions in Northern and Southern India—Immense extent of Madras irrigation—A few selected examples only possible—Kaveri delta canals—'Grand *anicut*'—The 'Upper' *anicut*—Effect of works -Area irrigated—Particulars of irrigation—Godavery delta canals—Outline of system and works—Weir at Dowlaishweram—Kistna delta canals—Kistna weir—Main canals—Pennair delta canals—Sangam irrigation—Srivaikuntham canals, and outline of system.

ALL the great 'Delta' irrigation schemes of India, with the exception of the Mahanadi in Orissa, of which we have already spoken, are situated in the Madras Presidency, and it is in Madras that this class of works originated. When the districts of Tanjore and Trichinopoli first came under British rule, a large amount of irrigation which had existed from very ancient times, was found in operation in the delta of the Kaveri and Kalerun rivers, by means of native works which had made these districts among the richest in India. The improvement of these old works—commenced in 1834, nearly sixty years ago—was, with the exception of the Western Jumna Canal in the Punjab, the earliest irrigation work carried out in India by the British Government. It is here that the characteristics and peculiarities of delta rivers, and the special adaptation of delta areas for purposes of irrigation on a large scale, were first studied and understood, and led to the extensive irrigation schemes since carried out in the larger deltas of the Mahanadi, Godavery, and Kistna, and elsewhere on the East coast. Madras Canals.

These great delta schemes, and the wonderful amount of irrigation carried on by means of storage reservoirs, of which we have already made mention, constitute the chief distinguishing

features of irrigation as practised in the Madras Presidency. South of the Mahanadi basin the general slope of the country is from west to east. A high range of hills skirts the whole Western coast from the Gulf of Cambay to Cape Comorin, and on this range the main portion of the South-west monsoon is precipitated. A large portion falls over the crest of the *ghâts* and abundantly supplies the sources of the greater rivers, which flow from the eastern slopes of the range, across the peninsula into the Bay of Bengal, breaking through the line of '*Eastern ghâts*' in their passage at varying distances, but comparatively near, their entrance into the sea.

Over all the central parts of the country the average rainfall is less than 30 inches, but below the Eastern *ghâts*—dependent on the North-east monsoon from the Bay of Bengal—the average annual rainfall lies between 30 and 40 inches. The great rivers, in ordinary years, bring down from the Western hills a practically unlimited supply of water, a supply, however, entirely dependent on the vicissitudes of the South-west monsoon, and which, owing to the heavy general slope of the country, is—if not intercepted—carried off with great rapidity.

The main crops in this part of India are grown from June to November, at the time when the rivers are at their maximum volume. Irrigation from the large rivers, therefore—unlike the conditions prevailing in Hindustan—is unlimited in average years. The Northern provinces of India possess in the snow-fed rivers of the Himalayan range, a regular and perennial source of supply, but on the other hand, the main crops being grown in the cold season, the area of cultivation has of necessity to be adapted to the comparatively small volume of water then available in the rivers. The essential distinction, therefore, between the ordinary conditions of Northern and Southern India is, that in the North, the area of main crops is restricted by a limited and more or less fixed quantity of water, whilst in the South the only limitation is the area of cultivable land. The North has the enormous advantage of a perennial, although limited supply, whilst the South is too often subject to the dire effects of a total or partial failure of the seasonable rainfall on which the irrigation depends. It is principally owing to this essential difference in the local conditions, that the extraordinary

development and wonderful extent of irrigation-work throughout the Southern Presidency, as compared with other parts of India, is to be attributed.

Outside the areas commanded by the large rivers, the country is mainly dependent on the comparatively small supply of water in the shape of local rainfall, or that brought up from the Bay of Bengal by the North-east monsoon. This supply is everywhere utilised, almost to the last drop. Throughout the whole of the Madras provinces, in every valley, arrangements of some kind exist for retaining, storing up, and utilising the water draining off its sides. There is scarcely a water-course which along its whole length is unprovided with a succession of dams, converting its course into a series of tanks, or reservoirs of greater or less dimensions, and along the foot of the Eastern *ghâts* almost every gorge offering the smallest facilities for the interception of the drainage by means of a dam, or dams, across its exits, is, or has at some time or other been so provided, and the precious water seized upon for the irrigation of the fields. The great body of water delivered by the South-west monsoon over the crest of the Western *ghâts*, and carried to the Bay of Bengal by the large rivers of the country—such, for instance, as the Godavery, with a current two or three miles broad and 25 feet deep—cannot necessarily be constrained to pay tribute to anything approaching an exhaustive extent, nevertheless a very large amount of this water is intercepted and utilised—especially at the head of the great Deltas by the splendid series of works, which have almost entirely been initiated and carried out by the British Government.

It would be impossible in the limited space available in this volume to give even a mere outline of each one of the large number of irrigation works initiated and constructed, or entirely remodelled and enlarged by the English Government in the Madras presidency; the purpose in view will be sufficiently attained by a selection of a few of the larger examples of each class of work, and a general summary of the whole.

There are eight principal systems of various size, classed as 'major works,' regarded specially as 'productive,' the expenditure on which has been incurred from Imperial loans, and twenty-one other works classed as 'minor provincial works'

carried out by provincial funds; of these last, three are large reservoir systems, and four are canals exclusively for navigation purposes. In addition to the above, there is an enormous aggregate number of smaller irrigation works of all classes administered by the irrigation department, but which individually are not sufficiently important to require separate capital or revenue accounts. Two large projects of the first class, estimated to cost £564,000 and £432,000 respectively, are (1893) under construction, but are not yet in operation. There are, therefore, thirty-one distinct systems, having separate capital and revenue accounts.

Kaveri Delta Canals.

The largest—as regards irrigated area—oldest, and also the most remunerative of these works, is the Kaveri Delta system, irrigating over a million acres, which is a development and enlargement of a very ancient native system of irrigation in Tanjore. The river Kaveri, rising on the Western *ghâts* and among the hills of Coorg, drains an area of about 28,000 square miles. It flows in a general easterly direction to the Bay of Bengal. The head of its delta—which has an area of 2700 square miles—is situated nearly 100 miles from the coast at a short distance above the town of Trichinopoli, where the river divides into two separate streams at the western extremity of Seringham, formerly an island, and still so called. The upper, or northern branch, is named the Kalerun. This branch, which in reality is the main drainage line to the sea, has a greater volume, a more direct course, and a far heavier fall per mile, than the smaller and more useful southern branch, which retains the name of 'Kaveri.'

The latter, after its separation from its main branch at Seringham, gains rapidly in elevation of bed, and flowing with a comparatively smooth and gentle current, soon divides and subdivides itself into numerous channels until its waters are spread over nearly the whole of the Tanjore district. In very ancient times, in order to counteract the tendency of the smaller and less rapid branch to become choked up with deposit, and to increase the volume of water passing down it, the large dam, or *anicut,* previously mentioned in the chapter dealing with native works, known by the name of the 'grand *anicut,*' was constructed across the river near the eastern, or lower end, of

Seringham island. This was the beginning of the delta improvement works, and its effect must have been of enormous benefit to the Tanjore irrigation. The supply of water, however, in later years became insufficient for the growing area of cultivated land in the delta, and the increasing amount of sand and silt, accumulating between the grand *anicut* and the point of separation of the two rivers, necessitated for many years the adaptation of various expensive expedients in order to prevent serious diminution in the supply of water.

In this state of affairs, when valuable and extensive tracts of rich country were gradually being thrown out of cultivation, Captain (afterwards Sir Arthur) Cotton, engineer of the Division, in the year 1834 devised and constructed the dam now known as the 'upper *anicut*,' across the Kalerun at a point about 100 yards below the bifurcation of the two rivers. This dam, obstructing only in a small degree the passage of high and destructive floods, at the same time diverted into the Kaveri all the water formerly carried wastefully into the sea, even in the driest seasons by the Kalerun branch, and rendered it available for the delta irrigation. Subsequently, in the year 1845, after the bed of the Kaveri had been deepened by the new volume of water thus thrown into it, a masonry regulating-dam was carried across that river on the opposite side of Seringham island.

The 'upper *anicut*,' or dam, is 2250 feet long, divided into three parts by two islands. It consists of a massive vertical wall of masonry, varying from 5½ to 7 feet high, supported on lines of brick-cylinders or wells, 6 feet in diameter, sunk to a depth of 6 feet into the sandy bed of the river. A stone flooring 30 feet wide and 4 feet thick extends below the dam to receive the overfall of water, below which again is an apron of rough stone about 20 feet broad. Twenty-two sluices were provided in the body of the main wall for the purpose of creating a scour, and prevent the filling up of the bed above the dam. The rise of the water in high floods above the bed of the river is 14 feet.

The effect of these works was to give a perfect regularity of current to the Kaveri river, and perfect control over the water passing down both streams. The Kalerun, with its heavy fall, is the main drainage outlet of the delta, whilst the Kaveri

below the regulating dam is practically converted into an irrigation canal. In the year 1836 another dam of similar construction to the 'upper *anicut*' was constructed across the Kalerun, some seventy miles below it. Its object is to intercept and divert some of the water in the intervening part of the river bed—which is increased by drainage from cultivation and by springs—for the purpose of irrigating large tracts of very fertile land in the north-eastern part of the delta, and in South Arcot.

Before the construction of these works the area irrigated dependent on the Kaveri and Kalerun rivers was but little over 600,000 acres; this area is now considerably over a million acres. The special peculiarity of the Kaveri delta irrigation is, that in all other cases of delta works the main distribution of water is carried on by means of a series of artificial channels, generally following a parallel course to the principal diverging river branches, but in the Kaveri delta the chief distribution is naturally effected by means of the river itself, and by the numerous branch channels thrown off by the Kaveri between the point of its separation from the Kalerun and the sea. From these branches innumerable distributing streams are led off to convey the water over all the village lands of the delta. To render this system effective it was necessary to regulate, divide, and sub-divide the water by regulating sluice-gates, placed at the head of all the main channels. In addition to these works, by degrees the various natural courses have for all practical purposes been converted into irrigation canals by straightening their channels and by correcting and making uniform the width of their beds. The whole has been rendered secure by various works, affording protection to the delta lands from the effects of inundation by flood-waters rising beyond what can be safely carried away by the irrigating streams.

In the Kaveri delta there are 844 miles in length of main irrigation channels, and 1250 miles of distributaries. In the year 1890-91 the area of land irrigated was 1,013,344 acres, with a total value of irrigated crops amounting to £2,530,345. Owing to the peculiar conditions and economical nature of the engineering works necessitated, the capital outlay has been relatively exceedingly small, whilst the area of irrigation affected

is exceptionally large. Hence the Kaveri system is the most remunerative in India, yielding a return of over 37 per cent. on the money expended by the British Government, and a large annual surplus revenue, after deducting interest charges.

The Godavery and Kistna deltas, lying between Cocanada and Pedda Gangam, on the East coast, adjoin one another, and form one extensive and connected irrigation area nearly 200 miles long and 50 miles broad. Both these rivers break through the line of the Eastern *ghâts*, within fifty miles of the sea, and in course of ages have built up the wide stretch of delta lands beyond them, for no doubt at one time the waves of the Bay of Bengal washed the base of the hills.

Godavery Delta Canals.

The head of the Godavery delta is at Dowlaishweram, from which point the river flows to the sea on an elevated bed, varying from 6 to 24 feet above the general level of the country. At Dowlaishweram the river forks widely into two branches, which we may call the 'Eastern Godavery' and the 'Western Godavery.' These branches divide the delta into three distinct areas, viz., the eastern delta, the central delta (lying between the forked branches), and the western delta. Each delta division is supplied with a separate system of irrigation canals, derived from the raised level of the Godavery, above a huge weir or *anicut*, which has been constructed at Dowlaishweram, just above the point where the single river separates and forms the eastern and western branches, and where the total width of the river is nearly four miles.

The Godavery works were commenced in 1844. The fine weir is one of the most magnificent of the many examples of such constructions in India. At the point where it crosses the river, the latter is divided into four portions by three intervening islands, which occupy about 3000 feet of the total width. The *anicut*, which, divided by the islands, may be considered as composed of four separate lengths of main weir, has a total length of masonry construction of 2½ miles. The Godavery drains an area of about 115,000 square miles, and as the rise of its water in floods at Dowlaishweram is 28 feet, it will readily be conceived that the construction of the enormous weir, to raise and control its waters, was a most exceptional and formidable undertaking.

The lengths of the four portions of the weir, which are the same in general construction, with only slight differences in dimensions, are as follows, 4872 feet, 2862 feet, 1548 feet, and 2584½ feet, respectively. In structure the work consists of a mass of stonework, some 130 feet wide at the base, 12 feet high, and 2½ miles long. The front and rear walls rest on two lines of brick wells, each 6 feet in diameter, and sunk 6 feet below the deepest bed of the river. The space below the walls is filled in with river sand and quarry spoil. The cross outline of the weir consists of, first a level floor or waste board of masonry, 19 feet broad and 4 feet thick, next of a slightly concave tail slope, which is practically an inclined plane, 28 feet wide, and also 4 feet thick; the upper surface in each case being protected by a covering of strongly-jointed cut stone; and lastly, of a rough stone apron of massive blocks, which extends some 80 or 90 feet down stream below the tail slope. On both sides of each length of weir masonry, wing-walls and lines of revetments connect the work with the main or island banks, as the case may be, and prevents the water passing round the extremities. Between each length of weir a substantial embankment of earth, protected by stone, is carried across each of the islands. On the extreme right and left flanks there are fifteen scouring sluices, each 6 feet in width, and on each main river bank, canal head regulating sluices and locks, each 100 feet long, are constructed. On the central island, forming practically the point of division of the two main branches of the river, is situated the head sluices and lock of the main canal carrying water to the central delta lying between the branches.

From above the Dowlaishweram weir three main canals radiate. One to supply the eastern delta has a bottom width of 184 feet, and carries eight feet in depth of water. One to supply the central delta is 114 feet wide, and carries 7 feet in depth of water; and one to supply the western delta—the water being here carried by several channels, but where collected together in one—225 feet wide and 10 feet deep.

From each of these main canals numerous branches issue, spreading over and commanding the greater part of the delta area, and generally terminating on the sea coast. One of the principal canals in the central delta is carried across a minor

branch of the Godavery on a fine brick aqueduct, having forty-nine arched openings, and a total length of 2248 feet.

Altogether, in the Godavery delta there are 506 miles of main and branch canals, of which practically the whole are navigable, and 1732 miles of smaller distributing channels. The cultivable area commanded is 772,000 acres, of which nearly all is under irrigation. In the year 1890-91 the value of irrigated crops raised was over a million and a half sterling, and the net revenue earned was nearly $12\frac{1}{2}$ per cent. on the capital outlay, with a surplus of £114,000, clear of interest.

Kistna Delta Canals.

The delta of the Kistna river, as we have already stated, immediately adjoins that of the Godavery, and is divided by the river into two portions, each of which is covered with irrigating channels, fed from main and branch canals derived from above an *anicut* or weir, situated at Bezvada, exactly at the apex of the delta, where the river narrows in its passage through a line of rocky hills on either bank. The Kistna weir was commenced in 1852. In position and in conditions of construction it is entirely different from that over the Godavery. Above and below the gorge across which the weir is thrown the Kistna has a width of nearly one mile and a half, but is contracted in its passage between the hills to 3900 feet. The velocity and depth of the current is consequently very great. The site was chosen, however, on account of the excellent supply of good stone immediately available. The weir is 3840 feet long, and consists of a single front wall of rough masonry, 16 feet high above the summer level of the water, 21 feet above the deepest bed, and 12 feet thick at the base. The wall is founded on a double row of wells 7 feet deep, which fill up the space between the deep bed and the lowest water level, around which a broad base of heavy stones was deposited. An apron of rough stone, 200 feet in width, extends below the weir, and at 100 feet from the latter a second parallel dwarf wall of rubble masonry, founded on the rough stone, was built after it had well settled. On each flank of the weir sets of scouring-sluices of fifteen openings, each 6 feet wide, are provided to keep a clear channel in front of the regulating head-sluices of the two main canals which there take off. In high floods the water rises nearly 20 feet above the top, or crest of the weir, with a

Tinevelly. Mention has already been made of the many ancient *anicuts* placed at intervals across the Tambrapurni, and the large amount of irrigation carried on by means of the numerous channels led off from it to feed old native reservoirs, which are dotted over the whole face of the country.

Notwithstanding this extensive irrigation, some portion of the Tambrapurni water still escaped to the sea, and to intercept and utilise this an *anicut* thrown across the river at Srivaikuntham, about 16 miles from the coast, was constructed and completed in 1874. From each side of the *anicut* main irrigation channels are led off, which convey water for irrigation purposes, over the whole of the tracts lying immediately north and south of the Tambrapurni, between the *anicut* and the sea. The canals irrigate directly, but chiefly serve to feed innumerable tanks, some of very large superficial area, which are scattered over the district. From the upper end of the Karampallam tank—the northern extremity of the series—a fresh-water channel provided with head sluices conveys water to the town of Tuticorin. The project, although of relatively small size, is yet of considerable value and importance. The Srivaikuntham *anicut* system has 28 miles of main and branch canals, and 62 miles of distributaries, irrigating about 30,000 acres.

CHAPTER VIII

MADRAS IRRIGATION

Madras irrigation continued—Soonkesala, or Kurnool-Cuddapah Canal—Guaranteed company—Early days of public works—Madras Irrigation Company—Employment of irrigation companies unsatisfactory—Kurnool-Cuddapah Canal the financial drag weight of Madras system of irrigation—Outline of project and main works—Weir over the Tungabhadra at Soonkesala—Course of main canal—Works on Pennair river—Peculiar features of Kurnool-Cuddapah Canal—Larger irrigation schemes in Madras—Minor canals too numerous for detailed mention—Main results—East Coast, or Buckingham Canal—Outline history of project and constructive features—Periar project—Description and scope of scheme—Particulars of concrete dam and principal works—General results of irrigation in Madras.

Madras Canals, continued.

Soonkesala, or Kurnool-Cuddapah Canal.

Leaving now the great delta schemes of the Madras Presidency, we will turn our attention to one of the principal works in the upper country, viz., the 'Soonkesala Canal,' or as it is officially designated, the 'Kurnool-Cuddapah Canal.' This canal presents the only example in India of an extensive irrigation work constructed by, and for a long period worked under the administration of, a guaranteed company. In early days all public works in India were projected and carried out by the Engineer Department of the army, working under a military board; and all expenditure incurred was charged against the revenue of the year, but as the necessity for opening up the resources of the country increased, it was soon found necessary to discriminate between the two great classes into which public works are naturally divided, viz., those of special and marked public utility, such as 'railways,' 'canals,' 'harbours,' etc., by which the wealth and prosperity of the country is directly promoted, and those works such as civil and military buildings, local roads, etc., whose chief end is to facilitate and render effective the general administration. The first class of works are virtually

large commercial undertakings, and these soon, of necessity, came to be constructed by means of borrowed capital; the second class remaining, as before, a charge against the general or local revenues of the year. In 1846, the construction of railways by companies, on whose capital expenditure the Government guaranteed a fixed interest, was initiated, and continued in force up to the year 1868. Two attempts only were made to apply the same system to the construction of irrigation canals. In the year 1858 the 'Madras Irrigation Company' was formed, which under a Government guarantee of 5 per cent. on a capital of one million pounds, undertook to carry out the works of the Kurnool-Cuddapah Canal, of which we are about to give an outline description, and a few years later the 'East Indian Irrigation Company' was formed, and undertook —but without any guarantee—the construction of canals in Orissa and Bengal. This Company carried out a good deal of work in the districts named, of which we have already made mention, but was bought out by the Government in 1867-68. The 'Madras Irrigation Company' constructed and administered for many years the existing Kurnool-Cuddapah Canal, but the works were eventually purchased, at a cost of over two millions sterling, by Government in the year 1882. Both these cases of the employment of companies for the construction of irrigation and navigable canals proved expensive failures to the State, the causes of which we are happily not here required to enter into.

The original Tungabhadra project—as the work we have now under consideration was then called—contemplated a canal for irrigation and navigation, derived from the Tungabhadra river, a few miles above Kurnool, passing *via* Cuddapah, and ending in the Kistnapatam estuary on the sea-coast a few miles south of Nellore. Only the portion between Kurnool and Cuddapah was, however, actually carried out, the work on which was practically completed by the Company in 1871. The remaining length of about eighty miles, between Cuddapah and the coast, or some modification of the original proposal which will place a large area of the interior upper country in convenient navigable connection with the 'East Coast Canal,' and with the capital city of Madras, will probably before long be undertaken.

The Kurnool-Cuddapah Canal is unfortunately the financial drag weight of the Madras system of irrigation works, failing at present to pay its ordinary working expenses, and showing a net deficit at the end of 1890-91 of over £800,000. It is practically the only irrigation project in the Madras Presidency, on which any important deficit occurs, the majority yielding a considerable yearly revenue. The canal commands the large area of 321,500 acres, but irrigates only about 25,000, whilst, owing to its disconnected position, the navigation traffic is small. The population of the districts affected by the canal are largely unused to wet cultivation, and the project—unlike the greater number in the Madras Presidency—does not so much afford facilities for the extension of an already highly-valued irrigation, but in reality introduces it for the first time, requiring for ultimate success the virtual substitution of a wet for a dry system of cultivation. The difficult character of the country through which the upper portion of the canal had to be carried has moreover weighted the project with a heavy initial outlay.

The canal begins at Soonkesala (17 miles above Kurnool), with a weir across the river Tungabhadra, 1500 yards, or not far short of a mile, in total length of clear overfall, which is broken into two lengths by an intervening island. This weir is constructed partly of solid rubble masonry, and partly of concrete, faced with masonry in front and rear. In height it varies from 6 to 26 feet, with an average height of 18 feet. The maximum flood waters pass at a depth of 7 to 8 feet over the crest.

The weir is built on the rocky bed of the river, and is not carried in a straight line across it, but follows in a serpentine course the line of the highest sound rock. The down-stream face of the weir wall in the highest portion is vertical; the water falling on to the natural gneiss rock below. Of late years the bed, especially below the scouring sluices, has shown signs of erosion and disintegration, necessitating a protective covering of masonry.

From the right-hand side of the pool above the weir the water is admitted into the canal by head-sluices, the river faces of which are kept clear by a line of ten under-sluices placed at

a low level in the adjoining weir; the current being forced across the line of canal sluices by a long curved spur, or 'groin.' The canal for the first 75 miles of its descent has a bottom width of 90 feet, and carries 8 to 9 feet in depth of water. In this length it has a very tortuous and difficult course, crossing many tributaries of the Tungabhadra by aqueducts, of which the principal is that over the Hindry, carrying the canal 90 feet broad, and 8 feet deep, over the river at an elevation of 32 feet above the bed, on fourteen arches, each of 40 feet span. The total length of the aqueduct is 651 feet.

At the 75th mile the canal passes through the watershed, or ridge of separation, between the Tungabhadra and Pennair drainage systems, by a long and deep cutting. From this point the natural watercourses of the country become the main-supply channels, the water being taken at four points by means of *anicuts* thrown across the Kali, Koondur, and Pennair rivers. Between the 75th and 95th miles the canal drops 180 feet through twelve locks, each 120 feet long and 20 feet wide, and between the 118th and 146th miles it passes through seventeen locks, with an aggregate fall of 187½ feet, the width of the canal being here reduced to 50 feet. At the 146th mile the canal touches the Koondur river at Rajoli, where a supply weir is thrown across the river. At the 172d mile the irrigation channel ceases. From thence to the river Pennair at the 181st mile (to which it descends 90½ feet through nine locks) the canal is a still-water navigation channel only.

The works on the Pennair river—which is crossed by the canal—consist of a masonry weir, with head and scouring-sluices, and an entrance lock, the gates of which are 25 feet high. The weir, which for the greater portion of its length lies on sand, is supported on double and single rows of wells, sunk deeply into the river bed. Below the down-stream slope of the weir there is a rough stone apron, 105 feet wide. Beyond the Pennair river the canal at present extends for a distance of 8 miles only, irrigating a small area. The length is in fact the first portion of the proposed extension to the coast near Nellore.

The peculiar feature of the Kurnool-Cuddapah Canal is the height and length of many of its embankments. These range

up to a height of 50 feet from the ground surface to the water-line in the canal, and are 35 and 40 feet high over long stretches. The banks are constructed in various ways, the largest being faced with masonry walls, supported by gravelly banks on the outside. Some have a core of clay, or 'puddle,' in the centre, on each side of which rough stone is packed. Others have a thickness of clay puddle on the inner face of the slope, overlaid with loose stone. There are altogether some 10 or 12 miles of these embankments, presenting somewhat novel and unusual forms of construction.

The total length of the Kurnool-Cuddapah Canal, which is navigable throughout, as at present constructed, is 190 miles, with 313 miles of distributing channels. As already stated, it irrigates only about 25,000 acres out of 321,500 acres commanded. In the year 1890-91 the value of irrigated crops raised was £70,050.[1]

The above works represent the most important of the large irrigation systems of the first class in the Madras Presidency. The eight works comprising this class, which have been constructed at a capital outlay of borrowed money of over $5\frac{1}{4}$ millions sterling, yield a yearly revenue of £372,000, or nearly 7 per cent. on their cost, and £174,000 annually after deducting interest charges. This revenue would be far greater were it not for the heavy loss sustained in the case of the Kurnool-Cuddapah Canal. The combined eight works irrigate an area of over $2\frac{1}{4}$ million acres, or 3666 square miles, and command upwards of 3,000,000 acres. Of the enormous number of the works of the minor class, constructed by provincial or local funds, there are twenty-one systems of a prominent character, of which four are exclusively canals for navigation. Space will not admit of any separate consideration of these works, which, however, include the numerous ancient tanks, or reservoirs, restored and maintained by the Government, some of which are of very great magnitude, such, for instance, as the Cummun and Chembrambaukam Tanks, of which we have already spoken in the chapters dealing with native works, as well as the 'Palar'

---

[1] Adapted from a paper on the 'Soonkesala Canal,' by J. H. Latham. *Vide Minutes of Proceedings, Institution of Civil Engineers*, vol. xxxiv.

and 'Lower Kalerun' *anicut* systems, each irrigating about 100,000 acres.

The comparatively few large 'productive' works, as they are officially designated, are of great value and importance, both to the people and to the State, but they are surpassed in local value by the aggregate of minor works of secondary individual importance. These minor works irrigate a total area of no less than 3,167,452 acres, or 5000 square miles, by means of 2422 miles in length of main canals and distributaries, and yield a yearly revenue of £435,000.

Of the four works constructed exclusively for navigation purposes, one only is of any special interest, and will serve as an illustration of this class of canal. The 'East Coast,' or 'Buckingham' Canal, is a salt-water tidal channel, extending along the east-coast of the Madras Presidency for a distance of 262 miles, of which 196 miles lie north of Madras city, and extends to Pedda Gangam, at which place it is in communication with the navigable canal systems of the Kistna and Godavery deltas. South of Madras city the canal extends 66 miles to Merkanum, a place situated about 23 miles from the northern boundary of Pondicherry.

Buckingham Canal.

The canal runs everywhere quite close to the sea, and is nowhere more than 3 miles distant from it. It has been constructed by degrees, at varying intervals, almost from the beginning of the century. The general features of the sea coast on this side of India consist of long parallel lines of sand dunes, lying along the shore, and between these dunes there are often considerable stretches of shallow depressions or hollows. These hollows, frequently forming backwaters, are filled with sea-water, and are of sufficient depth in many places for navigation, being supplied through the bars of the rivers, with which they are in connection.

So far back as the year 1801, the narrow strips of backwater found at the mouth of the river Kortalayar, suggested to a Mr. Heefke the idea of obtaining a Government concession to cut a canal, about 11 miles long, from Madras to the southern end of the Ennore breakwater. This permission was granted, and Mr. Basil Cochrane became surety for the projector. Mr. Cochrane subsequently obtained entire control of the work,

which he called 'Lord Clive's Canal,' and shortly afterwards he extended the navigation 16 miles further north, to Pulicat lake. This gentleman remained sole proprietor of the canal, with authority to levy tolls, for forty-five years, dating from 1802. In 1837, he having left India, the canal got into bad order, when his rights were bought out by the Government, who paid him at the rate of £1406 a year, up to the year 1847, when his lease expired.

This was the commencement of the 'Buckingham Canal,' then known as 'Cochrane's Canal,' a name which still adheres to the older portion, and later as the 'East Coast Canal.' In 1854 a lock was built 7½ miles north of Madras, partly as a sanitary measure, and to maintain a sufficient depth of water for the navigation. The channel was also extended to 69 miles north of the same place. About the same time the canal was excavated south of Madras 40 miles to the Palar river. At intervals, for many years afterwards, further extensions in both directions were made, the ultimate object in view being to effect a junction with the Kistna delta navigation in the north, and to connect the canal with the French possession of Pondicherry in the south.

In 1876-77, under the pressure of famine, it was decided that considerable extensions of the canal should be carried out by famine labour, and under the orders of his Grace the Duke of Buckingham, then Governor of Madras, large gangs of work-people from the famine-stricken districts of Bellary, Kurnool, and Cuddapah were marched down to the coast, and were set to work along the whole line. At one time it was reported that 100,000 men, women, and children were thus employed. On the termination of the famine the whole length of the existing Buckingham Canal—as it then came to be called—may be said to have reached a certain stage of completion. Subsequently, in the year 1883, funds were assigned for the full completion of the canal, from Pedda Gangam on the north to Merkanum on the south. The work throughout is of a simple character, consisting for the most part of a cut carried along the sand dunes, taking advantage of all the natural back-waters, having a bottom width varying from 20 to 30 feet, with side slopes from 2½ up to 4 to 1, according to the nature of

the material, and a depth of 3 feet below the lowest recorded tide in each reach. The several reaches of the canal, which intervene between separate drainages, are for the most part isolated by means of flood-gates, so as to exclude whenever desired all extraordinary floods, and at all points where drainage crosses the line of the canal the watercourses are trained, so as to preserve a deep channel for the passage of boats. The side embankments are made up to a level of 3 or 4 feet above the highest known water level.

The canal affords 307 miles of cheap water communication out of 387 miles, which intervene between the city of Madras and the Hyderabad coalfields, and also places that city in direct water communication with the well-irrigated deltas of the Kistna and Godavery rivers, and thus forms a most valuable line of connection during periods of famine.

Periar Project.

In the year 1884 a project of an exceptionally interesting and novel character, having some features of enormous proportions, was commenced, and is now approaching completion, in the Madras Presidency, of which it would be a great omission not to make mention in this outline description of the principal Madras irrigation works. South of the Kaveri river the districts of Madura and Ramnud depend for their supply of water (other than the scanty local rainfall) on the river Vaiga, which rises on the eastern slopes of the hills of Travancore. The streams which form its sources are very little affected by the south-west monsoon, here scarcely topping the crest of the *ghâts*, and the supply of water afforded is altogether inadequate for the wants of the districts named, which frequently have suffered severely from famines. It is said that not a drop of the Vaiga water reaches the sea, and that its channel in some years runs dry, even a few miles below the town of Madura. Yet whilst such a scanty and insufficient supply of water reaches the thirsty Eastern plains, the great river Periar, rising among the valleys on the other, or *western* side of the hills, under the the influence of over 100 inches of annual rainfall, carries an enormous volume rapidly down to the coast, where it is for the most part dissipated and lost in the backwaters of Cochin. The object of the Periar irrigation project, the works of which are now nearly completed, is to utilise a considerable portion of

this superabundant rainfall running to waste down the western slopes of the *ghât* by catching and diverting it to the opposite or *eastern* side of the dividing ridge. This is being effected in the following way. At a selected point in the upper valley of the Periar river a lofty dam will intercept the water draining from 300 square miles of its catchment basin, raising its level at the waste-weir of the dam to a height of no less than 144 feet above the deep bed of the river, and forming behind it an immense reservoir, storing 13,300 millions of cubic feet of water.

At a height of 113 feet above the bed of the river, at the dam, but at the opposite or upper extremity of the reservoir, a deep cutting is carried northwards for a distance of 5400 feet. At this point the cutting is replaced by a tunnel 6650 feet, or 1¼ miles in length, through which the water will be conveyed from the western to the eastern side of the dividing range of hills, and will be discharged into a tributary of the Vaiga river.

Of the total water stored in the reservoir, when full to the level of the two waste escapes, one on either side of the main dam, 6815 millions of cubic feet is available for irrigation in the eastern districts, and it is estimated that about 30,000 millions of cubic feet will be annually available. The Periar dam, which closes the valley of that river, is 220 feet long at the bottom, and 1200 feet long on its top line, and rises to a height of 155 feet above the deep bed of the river. On the summit is a parapet-wall 5 feet in height. The dam is being constructed entirely of concrete, made by mixing together hydraulic lime, sand, and broken stone; the latter obtained from the excavations for the escape weirs, occupying saddles in the adjoining rocky hillsides. At its highest portion the dam is 116 feet thick at the base and 12 feet thick at the top, 4 feet of the top width being occupied by the parapet wall.

On each side of the main dam the waste weirs have a length of 500 feet and 420 feet respectively, their crests being 11 feet below the top of the dam. The water falling over the escapes is received into basins, which form water-cushions below them. The rock-cutting, over a mile in length, conveying the water from the upper end of the reservoir to the mouth of the tunnel

or subterranean aqueduct is 21 feet broad, with a fall of 12 feet per mile, and it gradually increases in depth up to 30 feet, when the tunnel is commenced. The tunnel through the high portion of the ridge is 12 feet wide and $7\frac{1}{2}$ feet high, with a fall of 1 foot in 75. Suitable regulating sluices control the entrance of water into the tunnel, and are elsewhere provided as necessary, so that perfect control may be exercised over the movements of the water, whether at ordinary times or during periods of extraordinary floods. On the eastern side of the ridge various works are constructed to regulate the flow and distribution of the water.

The scheme, when completed, will provide irrigation for 140,000 to 150,000 acres of land, commencing at about 80 or or 90 miles from the head reservoir. The estimated cost of the project is £634,000. It is one which will be of enormous benefit to the districts affected, and will doubtless prove very remunerative after it has been a reasonable time in operation.

General results.

We can now briefly sum up the quantities and values resulting from the mass of irrigation works constructed in the Madras Presidency, as exhibited in the official returns, which—it should be remembered—only include those works under the care and administration of the Government Irrigation Department. Altogether, there existed in the year 1890-91, 3089 miles of main and branch canals, and 6627 miles of distributing channels (exclusive of a large mass of minor works, for which this particular detail is not given, but which, together, irrigate an area larger than that irrigated by the mileage of channels above stated). Of these canals, 1275 miles are navigable.

The area actually irrigated, including all the minor works, was 5,514,184 acres, or 8615 square miles. The capital outlay incurred by the British Government in the Madras Presidency on the major and principal minor works amounts to over $6\frac{3}{4}$ million pounds, yielding a net revenue of £751,000, and a surplus annual revenue, after paying interest on money borrowed, of over £550,000.[1]

[1] For details of individual works in the Madras Presidency, *vide* Appendix D.

CHAPTER IX

SCINDE AND BOMBAY IRRIGATION

Bombay and Scinde canals—Inundation canals in Scinde—General results—Bombay irrigation—Principal rivers—Main object of Bombay Irrigation Engineers—Area irrigated small as compared with other Provinces—Works of the first class—Jamda canals—Khrisna Canal—Ekruk Tank—Fife reservoir and Mutha canals—Nira canals—Bhatghar reservoir—Mhasvad reservoir—Hathmati Canal—Minor systems—Areas irrigated—General results of irrigation in Bombay—Concluding remarks, and general summary of irrigation throughout India—Recent review of irrigation works in India up to end of the year 1890-91—Conclusion—Note on Government classifications of canals.

ombay and inde mals. IN the British province of Scinde, on the lower part of the Indus valley, and forming a part of the Bombay Presidency, a very large area of cultivation is annually irrigated by means of a complicated network of inundation canals and their branches, originating in the Indus. The average rainfall in this part of India is barely 9 inches, and many localities may be said to be practically rainless. Unlike the rest of India, therefore, cultivation is here entirely dependent on irrigation, either from the canals or from wells. The annual rise of the Indus, due to the melting of the Himalayan snowfall, which commences in May, again subsiding in August—by which rise the inundation canals are fed—takes the place of the annual monsoon in other parts of the country.

In the previous chapters dealing with ancient native irrigation works, mention has been made of the enormous development, from very early times, of the system of inundation canals in the Indus basin, and of the main features of this kind of irrigation work. As the large majority of the inundation canals in Scinde are old native works, in many cases enlarged and improved under the British Government, it will not now be necessary to do more than indicate the general results of their working. Anything like a detailed description of these

numerous channels, which, although of the utmost simplicity in their constructive features, are yet in some aspects among the most interesting class of works in India, would nevertheless probably fail to enlist the interest of the general reader.

It has already been mentioned that the chief difficulty attending the working of these inundation canals is the incessant labour required to keep them clear owing to the enormous deposit brought down by the Indus. Formerly this constant clearance was effected by means of statute labour, and each cultivator was legally bound to furnish a number of labourers during the cold season, from December to April—when the clearances were chiefly effected—proportionate to the area of land cultivated by him. Statute labour was, however, abolished by the Government in 1856, and the annual work of keeping the channels clear of deposit, has since become the chief source of expense to Government in the maintenance of these canals.

The whole of the Scinde inundation canals are, for administrative purposes, divided into seven district groups, which contain an aggregate length of irrigation channels amounting to 5924 miles. To protect particular areas from excessive and violent inundation during the period of highest floods, there have also been constructed, and are maintained, upwards of 650 miles in length of protective embankments.

General results—Scinde Can

In the year 1889-90, the total area irrigated by the system of inundation canals in Scinde was 2,349,819 acres, or 3671 square miles. This area varies annually according to the extent and duration of the summer rise of the river. Four important canals, viz. The 'Desert Canal,' 'Unharwah,' 'Bigari,' and 'Eastern Nara Works' are classed as major (productive) works, and yielded a return of about 8½ per cent. on the capital expended, and show an accumulated net revenue of £153,237, after deducting interest charges. The numerically large group of works classed as 'minor' yielded an aggregate net return of 22 per cent. During the same year, the net revenue earned on the whole of the irrigation canals in Scinde amounted to £232,365.[1]

[1] For details of individual works in Scinde, *vide* Appendix E.

Bombay Canals. In Bombay proper, three principal rivers take their rise on the Western *ghâts*, and flow eastwards, viz., the Bhima, Krishna, and Tumbudra. These, uniting below Kurnool, form the single Kistna river, which, after traversing the Madras Presidency, enters the Bay of Bengal. Fed by numerous tributaries rising among the same hills the upper portions of these three rivers pass through the south-eastern section of Bombay, and their waters are utilised in various ways for irrigation. The difficulties, however, in the case of these larger rivers, are very great, owing to the comparatively slight fall of their channels, and the small volume of water they carry during the dry season. In the northern portion of the Presidency (excluding Scinde) the Nurbudda and Tapti rivers flow from west to east and enter the Arabian Sea.

The main object of the Bombay Irrigation Engineers, is, first, to retain and store up the ample supplies of water delivered by the south-west monsoon, and prevent its running to waste during the rainy months; secondly, wherever possible, to give it a sufficient elevation to command the dry and thirsty lands situated on the sides of the valleys of the country. For the most part the natives of the Bombay Presidency have not attempted to store the waters of the larger rivers; but small tanks on the minor tributary streams are very numerous.

As compared with the other provinces of India, the area of land artificially irrigated by means of large Government works in Bombay is very small, and, as a rule, the works that exist command a far larger area than they actually irrigate; the amount of irrigation being enormously affected by the occurrence of favourable and well-distributed monsoon seasons. In such years, principally owing to scarcity of labour, the crops which require to be matured by artificial irrigation are largely reduced in favour of other crops that are best matured by direct rainfall.

In the Bombay Presidency there are nine irrigation works of the first class in actual operation; and two projects are in course of construction. Works of the second or minor class number 27 in all. In actual operation, therefore, there are 36 separate irrigation works, the larger number of which are of small size and importance.

The earliest work of any consideration undertaken by the Government in the Deccan was the Jamda Canals, the construction of which was commenced in 1863. These consist of two canals, drawn, one from the right, and the other from the left of the Girna river, a tributary of the Tapti. The head works of these canals are situated at Jamda, in Khandesh, where a weir 1540 feet long, and 18 feet in maximum height, founded on a rocky bottom, is constructed across the river. The canal drawn from the left bank is 27 miles long, that on the right being 12 miles only, with 75 miles in all of distributing channels. A portion of the left bank canal was opened in 1866, and has therefore been in operation for 26 years. The right bank canal was not brought into use until 1878, owing to the small demand for water for monsoon crops. The canals command an irrigable area of 30,500 acres, but actually irrigate but a very small portion of this. **Jamda Canals**

In the same year, viz., 1863, a canal derived from the Krishna (the upper part of the Madras 'Kistna' river) was commenced, and was completed in 1868. Above the headworks of the Krishna canal, the river, rising in the Western *ghâts*, drains an area of over 1200 square miles, having a rainfall of 30 inches, it has therefore a considerable volume in the rainy season. A weir of rubble masonry, 1200 feet long, and 21 feet high in the highest portion, is built across the river, along a rocky barrier, which is situated at Korsee, close to the town of Karad, in the Satara district, where the Koina and Krishna channels meet each other. From above this weir the Krishna canal, 61½ miles in length is derived. The bed of the canal is 4 feet lower than the crest or top of the weir, which is provided with a line of scouring sluices. The canal is calculated to discharge 140 cubic feet of water per second, for eight months in the year; but in order to take advantage of freshes, the works are designed so as to be capable of passing 300 cubic feet per second, whenever such a supply is available. Provision is also made for constructing at the end of the rains a temporary earthen bank on the top of the weir, with suitable escapes at each end, in order to store water brought down by the slight freshes, which often occur in April or May. The Krishna canal commands an irrigable area of 25,533 acres, but irrigates only about 4000. **Krishna Canal.**

ıruk Tank. One of the finest of the earlier works of the reservoir class in Bombay is the Ekruk Tank, situated four or five miles due north of Sholapore. The construction of this reservoir was commenced in 1866. An earthen bank or dam, 7000 feet, or $1\frac{1}{3}$ miles in length, with masonry flanks, and 76 feet in maximum height, is reared across the valley of the Adhila river—a tributary of the Bhima. This dam is designed to raise the water to 60 feet in depth, when the reservoir is full, at which time the area of its water surface is 4640 acres, or $7\frac{1}{4}$ square miles, and its contents 3350 millions of cubic feet of water. The sites of five villages were submerged under its area. The surplus water passes over two waste-weirs, having a combined length of 750 feet, into a ravine channel, which rejoins the Adhila about a mile below the dam.

Three canals are fed from the reservoir, having an aggregate length of 48 miles. Two of these, drawn off at the high-level of 14 feet below the full water-line of the reservoir, are designed to furnish irrigation for four months in the year only, and are 18 and 4 miles long, respectively. The third or low-level canal, 26 miles long, is drawn off at 39 feet below full water, and is a permanent canal, providing perennial irrigation. Each of the three canals is capable of extension, commanding an additional area.

At present the total area commanded is 15,320 acres; but the area irrigated in 1890-91 was 2599 acres only, partly owing to a favourable rainfall in that year, but greatly due to a diminished capacity of the main canal in the first eight miles. This channel is designed to carry a maxium of 70 cubic feet of water per second; but only 30 cubic feet could be passed down it, pending some necessary repairs and improvements. The construction of the Ekruk reservoir dam was completed in 1869, but the canals were not completed to their present lengths for many years afterwards.

Fife Reservoir and Mutha Canals. Another exceedingly large and important combined irrigation and water-supply scheme is the Fife reservoir and Mutha canals system near Poona. This scheme was proposed by Colonel Fife, R.E., in 1863, and was commenced in 1868. The Fife reservoir has been formed by the construction of an enormous masonry dam across the valley of the Mutha river,

at a point about ten miles south-west of Poona. This masonry dam at the time of its construction was probably the largest work of the kind then attempted.

The Mutha river is a tributary of the Bhima, and rises in the Western *ghâts*, some 20 to 25 miles above the reservoir. The catchment area is 196 square miles, with an average rainfall of 34 inches. At the point selected for the reservoir dam, sound rock was met with near the surface. The dam is constructed of uncoursed rubble masonry—its length, exclusive of the waste-weir, being 3683 feet, the waste-weir being 1453 feet long. The maximum height of the dam, from foundation to summit, is 106 feet, or 96 feet above the lowest bed of the river. The crest of the waste-weir is 87 feet above the same point, or 11 feet below the top of the dam.

The contents of the reservoir when full is 5200 millions of cubic feet, and the area of the full water-surface is 3300 acres, or slightly over five square miles. In order to gain the elevation necessary to command the station of Poona, and the districts beyond, the level of the bed of the canals fed by the reservoir is placed at 59 feet above the river-bed. There is, therefore, 28 feet in depth of available storage between the bed-level of the canals and the crest of the waste-weir, representing 2680 millions of cubic feet of water, or a maximum of 3283 millions of cubic feet, when, at the end of the rains the water-level is raised some 4 feet above the top of the waste-weir, by means of posts and sliding planks which are fixed along the crest. It is estimated that during an average season the reservoir fills sixteen times, and that one-sixth of the whole discharge of the river is utilised.

Two canals are supplied from the reservoir, one, on the right bank of the Mutha, about 70 miles long, passes through the station of Poona, then turning to the eastwards, it irrigates a long tract of country lying in the dry zone of the Deccan, between the river and the foot of the hilly range to the south. The second canal, which is 14½ miles long, extends only a short distance beyond the military station of Kirkee, at which place water is supplied to the powder-works.

The total area irrigable by these canals is nearly 50,000 acres, but only about 11,000 to 12,000 acres are actually irrigated.

Besides providing for irrigation, the project is designed to furnish an abundant supply of pure water to the city, civil station, and cantonments of Poona and Kirkee, and to numerous villages lying along the course of the canals. A considerable portion of the yearly revenue is derived from this source. In the year 1890-91, nearly 277 million gallons were delivered from the canals for the Poona water-supply, the population of the area served being by the last census 32,242 persons, and the average consumption per head per day amounted to 23 gallons.

The water-supply for the city is drawn off at the 10th mile, and through the station of Poona—in order to avoid interference with public buildings and the parade ground—the canal is carried underground in two tunnels. At the end of the first tunnel, near the centre of the cantonment, there is an overfall, the force of which has been utilised to drive a large undershot water-wheel, which works a set of pumps for raising the canal water into the filter-beds, settling-tanks, and covered reservoirs of the high and middle-service systems of the water-supply. For the low-service system, mains and branches are led off directly from the canal itself.

Nira Canal. The 'Nira Canal' and Bhatghar reservoir, is a project carried out to a great extent in recent years. The main Nira Canal was opened in the year 1885. It is derived from the left bank of the river Nira, an important tributary of the Bhima at Vervadi, situated about 40 miles south-east of Poona. The completed length of the canal and branches is designed to be a little over 100 miles, of which $95\frac{1}{2}$ miles are now open, with 109 miles in length of distributing channels. The canal follows a very winding course along the foot of the high ground lying north of the Nira, passing near Baramati, and extending to Sudrapur, near the confluence of the Nira and Bhima. Numerous branches are carried down from the canal towards the former river, irrigating about 17,000 acres. The total area irrigable by the complete project is given as upwards of 227,000 acres.

Bhatghar Reservoir. The water-supply of the river is supplemented from a very large reservoir situated a few miles above the head of the canal at Bhatghar. The Bhatghar reservoir has a catchment area of

128 square miles, with an annual average rainfall of 145 inches. The water is retained by a masonry dam, 127 feet high above the lowest foundation, and 108 feet above the river-bed, forming above it a huge lake, containing an available storage-supply of 5500 millions of cubic feet, and having a water-surface area of 3584 acres, or more than $5\frac{1}{2}$ square miles. The estimated cost of the complete work is £637,000.

Mhasvad Tank.

Another recently constructed reservoir of great size is the Mhasvad Tank, in the Satara district. An earthen embankment, 80 feet high, closes the valley of the Mau river, cutting off a catchment basin of 480 square miles, having, however, but a small annual rainfall. The reservoir stores an available water-supply of 2633 millions of cubic feet, and has a water area of 4013 acres, or $6\frac{1}{4}$ square miles. The reservoir feeds 27 miles in length of main irrigation canals, and $66\frac{1}{2}$ miles of branches and distributaries, which first came into operation in the year 1887. In that year the canals irrigated but little over 1000 acres, but by the year 1890-91 this had increased to 7106 acres. The total acreage irrigable by the existing works is 106,000 acres.

Hathmati Canal.

The Hathmati Canal was commenced in the year 1869, and was brought into partial operation in 1873. It is derived from the Hathmati river—a tributary of the Salarumati, about 40 miles above the town of Ahmedabad. The head-works of the canal consist of a weir of rubble masonry, 1000 feet long, and 22 feet in maximum height. From the pool above the weir the canal, which is 21 miles long, with 30 miles of distributaries, is drawn. The canal commands an irrigable area of 8000 acres, of which it actually irrigates rather less than half.

The above works comprise all the more important of the Bombay irrigation projects of the first class. Space will not permit any separate mention of the numerous minor systems of the secondary class, which number twenty-eight in all. These Government works, however, are very far from representing the true extent of irrigation carried on in the Bombay Presidency. The thirty-six major and minor works taken together irrigate only about 76,000 acres of cultivation; but, in addition to this area, over 145,000 acres are irrigated by the aggregate mass of still smaller works, 1270 in number, scattered all over the Presidency districts, which are looked after and kept in repair

by the Irrigation Department. For the most part these lesser works consist of small tanks, and of weirs called *bhandaras*, on the smaller streams, the larger number being of ancient or modern native construction. In the Dharwar district alone there are said to be 473 tanks, irrigating 65,000 acres.

General results—Bombay canals.

According to the official returns, there are in the Bombay Presidency 606 miles of main canals and branch canals supplied with 564 miles of distributing channels. During the year 1890-91, 221,464 acres of land, or about 34½ square miles, were irrigated, yielding a total value of irrigated crops of nearly £400,000. The total capital outlay by the Government on all classes of irrigation works in Bombay was £2,465,024, earning a net revenue of £56,033, or 2·2 per cent. on the capital cost. Including interest, however, the thirty-six works of the major and minor class resulted in a deficit of £70,743. The mass of smaller agricultural works taken together yielded a profit of £33,913, giving a net deficit of £36,830.[1]

We have now sketched in general outline the main features of the irrigation works of British India, both as regards the type and character of early native constructions, and the extensive improvements and additions introduced by modern engineers since the country has been brought under British rule. The picture we have been able to draw is, of necessity, projected on so small a canvas as to be altogether inadequate to convey to the eye more than a mere outline of individual works—nor has it been attempted to do more than this. The object aimed at has been to implant in the mind of the reader a fairly correct impression of a great whole by means of a rapid exhibition of the general dimensions, number, and value of its main component parts. To do this, it has been unfortunately, but unavoidably, necessary to quote largely figures expressing volumes, areas, and linear dimensions, as well as money expenditures and revenue returns, which, it is feared, may have unduly taxed the patience of the reader. Nevertheless, in conclusion, it will perhaps serve to impress more firmly on the mind what we especially desire to imprint, if the main figures and results of irrigation works throughout British India are

---

[1] For details of individual works in the Bombay Presidency, *vide* Appendix F.

finally summed up in one general statement, the reader being careful to bear in mind that these totals are approximate only; some of the figures entering into them being for the year 1889-90, and others for the year 1890-91. Although not, therefore, comparable with the statistical data of any single year, they will nevertheless serve the only purpose we have in view, viz., to convey to the reader a general and approximate idea of the large total value and extent of irrigation and navigable canal operations in India, exclusive, it need not be said, of that large amount of secondary irrigation carried on by unassisted native agency.

In the whole of India about 16,000 miles of main and branch canals have been constructed by the British Government, of which 2882 miles are navigable. These canals distribute their waters by means of over 23,500 miles of minor channels, and irrigate from 12 to 13 millions of acres, or about 20,000 square miles of country. The annual value of irrigated crops, excluding Scinde, for which the figures have not been obtained, is probably not far short of 30 million pounds. The capital sum expended by the Government on all classes of irrigation and navigation canals throughout India is a little above the same amount, and the net revenue annually earned is nearly 1¾ millions sterling, or about 5½ per cent. on the capital cost. The sum realised, after defraying interest charges, is over £725,000 annually.[1]

In a recent review of irrigation works up to the end of the year 1890-91 by the Government of India, dealing with those works for which both capital and revenue accounts are kept, the directly remunerative character of the total outlay incurred on irrigation throughout the country is clearly exhibited. As this review is based on figures far more complete than those we have been able to utilise, and is moreover brought up to a uniform, and in some instances to a later, date, the following general results will be of interest. It is shown that, for irrigation works only, the capital expenditure on major 'productive' works to the end of 1890-91 amounted to £25,465,011, yield-

[1] For approximate total results of irrigation and navigation canals in all India, *vide* Appendix G.

ing a net return of 4·81 per cent., without taking into account the old irrigation in Madras. Including this, the net return is given as 5·80 per cent., whilst including 'protective' works, and that portion of the minor works for which capital and revenue accounts are kept, the total percentage of net revenue on capital outlay is shown to be 5·69 per cent. The protective works taken alone yielded 0·79 per cent.

The direct capital outlay on navigable canals, including both major and minor works, is £1,887,033, the net revenue being 0·82 per cent. on their cost.

Altogether, on 120 works of irrigation and navigation, costing £31,620,310, the net revenue derived in 1890-91 was £1,710,136, or 5·40 per cent., and the area of land irrigated, excluding the lesser classes of minor works, was 9,275,102 acres, or nearly 14,500 square miles.[1]

These results include figures relating to projects such as the Chenab Canal, the Sangam, and the Periar works, which, being incomplete, yielded nothing on their capital outlay. The very unremunerative Orissa and Kurnool-Cuddapah canals are of course included. It is stated that 'on the whole, the returns from the systems which fulfil the conditions of being productive, are more than sufficient to cover the deficits on systems which, although classed as productive, do not attain to the necessary standard.' The estimated value of the produce for one year on all the irrigation canals of India is shown to be nearly equal to the whole of the direct capital outlay incurred on the works.

A list is given of important irrigation projects that have been submitted to the Government of India, but upon which work has not yet begun. These are, the 'Jhelum Canal,' the 'Kalingaroyen channel,' the 'Chenab extension project'—all of which have been sanctioned—and the Cawnpore branch of the Lower Ganges canal, a project which is under preparation. The additional area that will be irrigable by the above works amounts to 1,291,000 acres, or 2017 square miles, and the estimated returns are calculated at over 13½ per cent. The Chenab Canal extension is to take precedence over the Jhelum Canal. A considerable and profitable outlay is contemplated

---

[1] *Vide* Appendix II.

on works in Upper Burma, where scientific irrigation has as yet hardly commenced, and proposals are awaited from the Bombay Government for the improvement and extension of irrigation works in Scinde, upon which question a committee assembled early in 1892.

In conclusion, if we placed end to end all the main and branch canals of India, they would reach nearly two-thirds of the distance round the world, and the navigable portion would be represented by two canals—one stretching from Cape Comorin to Peshawar, and the other from Calcutta to Bombay, a combined distance equal to nearly the whole breadth of Europe. The minor distributing channels, placed together, would extend almost completely round the earth's circumference.

Note.—Under the Government system of accounts, irrigation and navigation works in India are divided into two main classes, respectively called 'major' and 'minor' works. The major class comprises all those works estimated to be directly 'productive' within ten years from completion, and certain special works called 'protective,' primarily undertaken to protect certain districts from famine, whether likely to be directly profitable or not.

The second or 'minor' class is, for accounts purposes, divided into several sub-classes, viz.:—

(1.) Works for which both capital and revenue accounts are kept.
(2.) Works for which only revenue accounts are kept.
(3.) Works for which neither capital nor revenue accounts are kept.
(4.) Agricultural works (sub-divided in the same manner), being chiefly river embankments, etc.

The quantitative and financial results of irrigation works, as exhibited in general Government returns, relate only to those works for which both capital and revenue accounts are kept. The exact total figures for the last three sub-classes of 'minor' works not being available, these are necessarily excluded from general statements of irrigation operations.

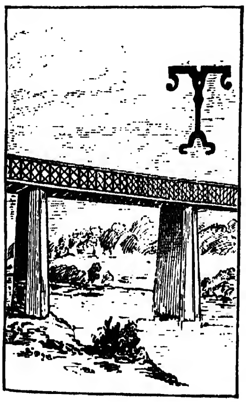
Collectively, however, these lesser sub-divisions of the minor works class are of importance and interest. So far therefore as it has seemed possible to ascertain and extract them from the various provincial returns, we have included them in the totals of the tabular statements A to G, which will be found as an Appendix at the end of this volume, as well as in our general summary of irrigation works throughout India.

RAILWAYS IN INDIA

CHAPTER I

ORIGIN OF RAILWAYS

Origin of railways—Wonderful influence in regenerating India—Caste-barriers largely affected—Reduction of distances—Birth of the locomotive engine—Rude germs of a line of railway in old Italian stone tracks—Timber wheel-roads in colliery districts—Tramroads—Use of cast-iron for rails—'Edge' railway—Early inventors and improvers—Steam-power—Stationary engines and horses—Messrs. Trevithick and Vivian—Mr. Thomas Gray—The man with one idea—His book on steam land-conveyance—Working out practical details—Mr. Blenkinsop—George Stephenson—Sketch of his life and work—Stockton and Darlington Railway—The Quaker family of Pease—Opening of the Stockton and Darlington line—The 'Experiment'—The Liverpool and Manchester Railway—Motive power—Premium offered for best locomotive—Public trial—Success of the 'Rocket'—Causes of superiority—Condition of early railroads in England—Extract from a speech by George Stephenson.



Origin of Railways.

THERE is perhaps nothing more surprising to be met with in the history of human progress than the startling rapidity with which the lives and habits of mankind have been beneficially revolutionised by the introduction of steam locomotion. Compared with the effects of any other social influence that can be named, this rapidity is only fitly to be measured by the difference between the speed of an express train, and that of all former instruments of human progression.

If we reflect how very slow in operation, and how very gradual in results great social movements usually are, it becomes truly

startling to consider that the whole of those wonderful ramifications and systems of railways and ocean steam-lines of transit, which in modern times have so profoundly modified the fundamental conditions of human intercourse, and which to-day bind together every part of the civilised world, and bring into such close and intimate relations the inhabitants of every civilised country, is the growth of a period of time well within the limits of an ordinary human life. That all those facilities of movement and intercommunication to which we have grown so accustomed, and which now appear to us so indispensably necessary to the prosecution of the most ordinary business and pleasures of existence, have been virtually acquired under the rule of the present reigning sovereign of Great Britain.

In the Western world the diffusion of happiness and prosperity, and the entirely altered conditions of human progress which attended the invention and introduction of the locomotive engine was surprising enough, but for some period before its introduction, especially into England, the extensive use of navigable canals, and the rise and ultimate prevalence of excellent lines of good macadamised roads, with the employment of an organised system of fast and well-appointed coaches between important centres for passenger and for the lighter forms of commercial traffic, materially smoothed the transition, and gradually paved the way to that more rapid means of locomotion, and that manifold multiplication of productive energy subsequently inaugurated, and rapidly developed by the railway system.

It is in the relatively roadless East, and particularly in the great continent of India, that we are enabled to witness in its full proportions the extraordinary awakening, and the wonderfully rapid subversion of previous habits of life and thought, which has been so notably effected within the space of a few years, by the operation and under the regenerating influence of railway communication.

The generality of Europeans, on grounds of a sufficiently extended experience, have long been accustomed to regard the Asiatic as a being passively, but hopelessly, resistant to all forms of innovation; as apathetic, torpid, unenterprising, and incur-

ably wedded to the practice and routine of bygone centuries; but in our own day it has been reserved as one of the most remarkable triumphs of the steam locomotive to have aroused and awakened the Eastern world, to have undermined, and in great measure overturned, the larger number of those deep-rooted ancient prejudices which in India have so long and so tenaciously resisted all previous assaults.

The strong barriers of one of the most rigid and exclusive caste systems in the world have been penetrated on every side by the power of steam. In India for many years past, caste prejudices have been practically extinguished within the fences of a line of railway, and the most sacred Brahmin will now contentedly ignore them rather than forego the luxury and economy of a journey by rail, whilst everywhere the usually imperturbable and lethargic Eastern has been aroused out of sleep, has learned to move with alacrity, and even to acquire the virtue of punctuality, under the uncompromising and imperious tuition of the locomotive whistle.

Railways in India have reduced the effective size of that continent to less than one-twentieth of its former dimensions, so that places situated 400 miles from the home of an intending traveller or producer of goods for the market, are now as practically near to him as others only 20 miles distant formerly were, and journeys which would have occupied the time, imposed the fatigue, and consumed the daily charges of the best part of a month, can now, with ease, comfort, and economy, be performed within the compass of a day.

To attempt an adequate delineation of the enormous social, commercial, and other advantages which India has derived from railway communication would carry us beyond the limited space at our disposal, and would, moreover, in these days be as superfluous as a thrice-told tale. 'It may be said, without undue enthusiasm or exaggeration, that this great invention has imparted a stimulus and a vital energy into all the affairs of man, whether connected with business or pleasure; has multiplied in a manifold degree our capacities and opportunities of enjoyment; has vastly increased the volume of trade and manufactures in the country; and has in a thousand ways contributed more to the happiness

and welfare of our race than any other discovery or invention that could be named.'[1]

The story of that portentous birth, which ushered into the world the infant Hercules of the nineteenth century—the early and vigorous efforts of its sturdy iron members, irresistibly impelled by the imprisoned and forceful spirit of its mighty solar ancestor. In other words, the story of the conception and birth of the locomotive steam-engine, and the consequent rise and development of the railway system, is one of perennial and of the deepest interest to mankind. The story has been written and re-written with the most loving care, and in the most eloquent detail by numerous able pens. Nevertheless, to the younger rising generation, especially in India, the interesting narrative may be less familiar than to the children of those in whose immediate presence the stirring events of railway history were enacted. It will possibly, therefore, not be altogether unprofitable if, before recounting the introduction and growth of the railway system of India, we cast a brief retrospective glance at the early history of the locomotive and of the railway in the land of its inception and birth.

The first rude germs of a line of railway are probably to be found in the smooth parallel stone tracks, which were laid down for draft purposes in the streets of many of the older Italian cities. In England the practice of laying down timber wheel-roads in the colliery districts of the North, and elsewhere in the neighbourhood of mines, for the easy passage of heavily-laden vehicles drawn by horses, appears to have arisen as early as the beginning of the seventeenth century. These timber wheel-tracks obtained the name of 'trams,' or 'tram-roads'—supposed to have been a popular abbreviation of the name of a Mr. Outram, who either originated, or at an early date was extensively connected with their employment. They appear, however, to have been also called 'way-leaves.' Roger North, writing in the year 1676 with reference to a visit paid by his brother, Lord Guildford, to the neighbourhood of Newcastle, mentions this name, and says: 'When men have pieces of

[1] Paper read at the Society of Arts, February 14th, 1890, by Geo. Findlay, Assoc. Inst. Civil Engineers, on *Modern Improvements of Facilities in Railway Travelling.*

ground between the colliery and the river they sell *leave* to lead coals over the ground, and so dear, that the owner of a rood of ground will expect £20 per annum for this leave. The manner of the carriage is by laying rails of timber from the colliery down to the river, exactly straight and parallel, and bulky carts are made with four rowlets fitting these rails, whereby the carriage is so easy that one horse can draw four or five caldrons of coals, and is of immense benefit to the coal merchants.'

It was not, however, until about one hundred years later that these wooden tramroads were superseded by the employment of cast-iron plates, laid on the surface, and firmly bolted to the timber-ways. At Colebrook Dale, about the year 1760, it happened that the price of iron was exceptionally low, and the demand for it was so small that, rather than close the furnaces, the owners decided to cover the upper surface of their wooden tramroads with plates of cast-iron, in order to decrease friction, and render the ways more durable. It was thought that, in case the price of iron suddenly rose, these plates could be lifted and sold as 'pig' iron. The advantages, however, of the cast-iron surface were soon found to be so great, that instead of the plates being removed, their use was gradually extended over the whole district; and before long tramways exclusively of iron, supported on blocks of wood or stone, came into extensive use, especially in South Wales, where by the year 1811, 180 miles of such tramways are said to have been completed.

The first solid iron rails that appear to have been used were cast in section like an ordinary angle iron, in short lengths of from 3 to 5 feet, and they were frequently spiked down to cross supports of wood, named 'sleepers,' let into the ground. The vertical flange of the angle-iron rail was always placed *inside* the wheels of the vehicles, which rolled along the flat, or horizontal portion. Various other sections of 'metals,' as they soon came to be called, were tried in the different mining districts of England and Wales. One of the most successful was the 'edge' railway, introduced into the slate quarries of Caermarthenshire. In this tramroad—or railway, as it truly was—the rail was supported above the level of the wooden cross-

sleepers, and had a flat or slightly rounded top or 'edge.' The guiding flange was transferred from the rail to the wheels of the vehicles or 'wagons,' which in the first instance were made with flanges on each side, forming a grooved wheel-rim, which fitted over the rail-head. This double-flanged wheel was soon found to be unnecessary, and a single projecting flange inside the rail was presently adopted. The ends of the 'edge' rails were secured into an iron box or 'chair' of cast-iron, securely screwed down to the sleepers. So remarkably easy was the haulage on this rail- or tram-way, that it was found that two horses could rapidly draw a train of wagons weighing up to 24 tons, and the effective service of the two horses was calculated to be equivalent to that of 400 working on a common road-surface.

The various forms of horse-tramroad in use were for a long time entirely confined to the vicinity of mines and to the purposes of mineral traffic, but in the very early years of the present century the improvements effected in their construction, and the wonderful success and economy of these roads, began to attract a wider attention. Many ingenious minds bestirred themselves, and numerous enthusiastic projectors began to bring forward proposals for their more extended application in the service of the general public. A Dr. Anderson, in the year 1800, proposed that iron rails should be laid down along the sides of the principal turnpike roads, and be at the service of all who might choose to employ them under suitable regulations. Subsequently he advocated the construction of independent lines of way, having easy gradients and curves, bridges, and even tunnels. The idea was so far realised that in 1801 the 'Surrey Iron Railway Company' obtained an Act for the construction of a horse-tramway for general merchandise, from Wandsworth to Croydon, and experiments were made which showed that a single horse could draw on the level, at the rate of 6 miles an hour, twelve wagons each laden with three tons of stone—or thirty-six tons—a load subsequently increased to more than fifty-five tons.

At this time the use of steam was already known as a motive power, and it had been successfully applied for the working of stationary pumping engines in numerous mines throughout

England and elsewhere. In the mining districts the tramroads employed in the mineral traffic generally descended from the neighbourhood of the pits' mouth to the wharves, usually situated on some river in the valley below, so that the inclinations of the roads were in favour of the loaded vehicles. When the difference of level was very great, as it often was, it was common to manage the descent, not by making the road one uniform inclined plane, but by interposing one or more steep slopes; the remainder of the way being kept tolerably level. The laden wagons were allowed to run down the steep inclines by their own weight, and very often by the aid of a rope and pulley; the descending heavy wagons were made to pull up the return or empty ones.

It soon became general, however, during the first decades of the century, to employ stationary steam-engines for hauling the empty wagons up the steep inclines, while horse labour continued to be everywhere used on the other or more level parts of the tramroad. In this way steam-engines and horses came to be associated almost side by side, and shared the work between them, and men's minds gradually began to entertain the idea of uniting the two, so as to produce a movable engine or 'steam-horse.' Various experiments with this object in view were tried in different parts of the country. Even so early as the year 1804 a rude locomotive machine, worked by steam and moving on rails, was tried at an ironworks in Wales. Messrs. Trevithick & Vivian, engineers, produced several steam-locomotives with some measure of success, and before very long in a good many of the colliery districts small locomotives might be seen which, 'with much clanging and rattling, puffing and smoking, from both steam vent and chimney, drew along at the sufficient pace of 2 or 3 miles an hour, a dozen or more small iron wagons laden with coal; a man would walk by the side to open gates, remove impediments, and assist at a difficulty. The colliers themselves would sometimes jump into the empty wagons, as a tired carter will get into his empty dung cart, or sit on the shaft.'[1]

Such was the general state of matters about the year 1819,

[1] *Our Iron Roads.* By F. S. Williams.

when some one remarked to the celebrated canal-making Duke of Bridgewater, 'You must be making handsomely out of your canals?' 'Oh, yes,' he replied, 'they will probably last my time, but I don't like the look of these tramroads, there's mischief in them.' What the shrewd Duke foresaw, no doubt, many other persons may have vaguely anticipated, but it is the persistent man of 'one idea' who generally succeeds in fixing and forcing the attention of the public mind. Such a man was Mr. Thomas Gray—the really first public proposer, in the year 1820, of a general system of transit by railways. Mr. Gray, according to the well-known story, which marks the first awakening of his 'idea,' was travelling about the year 1819 in the North of England on commercial business, and one day stood looking at a small train of coal wagons impelled by a snorting and puffing steam-engine along a tramroad which connected one of the collieries of that district with the wharf at which the coals were delivered. 'Why?' he asked of the engineer, 'are not these tramroads laid down all over England, so as to supersede our common roads, and steam-engines employed to convey goods and passengers along them so as to supersede horse-power?' The engineer looked at the questioner with an amused smile: 'Just you propose that to the nation, sir, and see what you'll get by it. Why, sir, you'd be worried to death for your pains.' Thomas Gray made no reply, but went thoughtfully away—the *idea* had firmly lodged itself into his brain, and worry or no worry, he could not get rid of it—railroads, steam-engines, horse-power and common roads superseded—the words kept repeating themselves over and over again; he could think of nothing else; he could *talk* of nothing else. He soon became a bore and a nuisance to his friends and acquaintance, and was doubtless regarded by them as more or less deranged. 'Railroads, steam-engines, horses and common roads superseded'—nobody would listen to him, and the engineer's words seemed likely to prove true. But the 'idea' of Thomas Gray was a genuine and workable idea, and would not allow itself to be suppressed. The pregnant words were dinned with renewed energy into the private and public ear by innumerable letters to friends, to newspapers, by circulars, pamphlets, and at length by a printed book, the first edition of which was

published in 1820, with the lengthy title: 'Observations on a General Iron Railway, or Land Steam Conveyance, to supersede the necessity of horses in all public vehicles, showing its vast superiority in every respect over all the present pitiful methods of conveyance by turnpike roads, canals, and coasting traders, containing every information relative to railroads, and locomotive engines, by Thomas Gray.'

Slowly the man of one idea emerged from the crowd. A few commercial men began to entertain a glimmering notion of his meaning, and to become interested. People of note looked at the idea, discussed it, and ended in advocating it almost as enthusiastically as Mr. Gray himself; even timid capital began to listen to it, and to come to its aid, until at last the minds of business men were sufficiently aroused to give the proposed scheme its first great public trial on the road between Liverpool and Manchester. This, however, was not until four or five years of persistent agitation, and after several editions of Mr. Gray's book had been published. The trial on a large scale was made, and suddenly the idea ceased to be at all wonderful, or even novel. It was only what everybody had always firmly entertained, and what everybody took the credit of.

The merit of first advocating a novel and workable idea, and persistently and successfully forcing it on public attention is undoubtedly very great, even allowing that in a very short time some other person would infallibly have done so. But it is to the practical workers-out of *detail* that the success of railway locomotion is really due. The solitary engines that here and there throughout the country laboured with so much difficulty along the tramroads, at 2 or 3 miles an hour, or if a greater speed was attempted at once broke down, and had themselves to be ignominiously hauled away by horses, would never have emerged from their first obscurity, and have revolutionised the world, if patient practical minds had not long and painfully laboured to evolve workable simplicity out of that wonderful complexity which is always the first offspring of the inventive genius of man.

It was believed that there never could be sufficient adhesion between the wheels of the locomotive and the iron rails, and it was found in many of the strangely-compounded early tramroad-

engines, that if the speed was at all augmented the driving-wheels would revolve on the smooth rails without advancing the load a single yard. The ingenious Mr. Blenkinsop at once devised the remedy. The plan was to notch the rails in the form of a rack, and the wheels of the engine and wagons were cogged with teeth to work into the notches. One of Mr. Blenkinsop's engines of 4-horse power impelled a carriage lightly loaded at the rate of 10 miles an hour, and hauled a train of thirty coal-wagons at about a third of that pace. Fortunately it was soon discovered that the conclusion on which Mr. Blenkinsop and others had been working was too hasty, and that the amount of adhesion between a smooth wheel and a smooth rail could easily be made quite sufficient for all purposes of traction.

The united labour and experiments of numerous practical mechanics throughout the United Kingdom were devoted to perfecting almost piece by piece, and joint by joint, the iron anatomy of the infant locomotive, until there presently emerged, and towered above his fellow-workers, a man whose name has become a household word, and whose title of originator of the modern locomotive engine is beyond dispute.

George Stephenson, the first of the great locomotive and railway engineers, rose to eminence from the humblest ranks of labour. His father was a working collier, and the son from his earliest years was dependent on the hard toil of his hands for his daily share of bread. He was born in a small cottage in the village of Wylam, on the banks of the Tyne, not far from Newcastle. As a young child he was sent out to work in the fields, from which he was shortly promoted to the more lucrative employment of picking over coal heaps at twopence a day. So young was he when thus engaged that he was obliged carefully to keep out of sight of the overseer, lest he should be considered too small to earn even this moderate wage. In his early manhood he was successively employed as a 'brakesman' on a tramroad, and as a stoker to a winding engine at the wages of a shilling a day. When this was doubled he is recorded to have declared himself 'a made man for life.' Steadily working and toiling, often having to rise at one and two o'clock in the morning, and labour until late at night, he struggled

with his destiny, but at so low an ebb were his fortunes in the first years of the century that he had almost decided to emigrate to the new world. Happily, however, for his country, he continued resolutely to battle with the difficulties of his life in his native district, where, as time went on, he gradually earned the character of a steady, observant, and resourceful man. At the age of 22 he married, and in 1803 his only child Robert was born—a child destined to become, in the world of railways, the peer of his distinguished father. As this son grew in years, it is related that George Stephenson, in order to meet his increasing responsibilities, and especially to provide for his son's education, had to turn his hand to almost every variety of work. It is recorded amongst other items that he taught himself to mend his neighbours' clocks and watches, to cut out clothes, make shoes for the pitmen and his poorer relatives, and, above all, to read, write, and to seize every opportunity of improving his mind.

His inventive genius was almost constantly at work, and so great was the local reputation that his steadiness, ingenuity, and sturdy integrity of character at length obtained, that about the year 1812 he was intrusted by Lord Ravensworth, and the Killingworth colliery proprietors, with money to make a practical trial of a locomotive engine, on which his time and thoughts had been for some time engaged. The engine was built and tried on the Killingworth tramway in the month of July 1814, and from this date the future railway engineer became in reality what he had himself anticipated at a much earlier period, viz., 'a made man for life.' His name and abilities became known over the whole of the Newcastle district. Engine stoking was left far behind, he became viewer at a colliery and engine-wright, was employed in laying down a tramroad at Hetton, and then, for the modest sum of £115, undertook to execute the survey for a proposed tramway, or railroad, from Stockton to Darlington, and afterwards became principal engineer to that line, to which we must now for a moment turn our attention.

For many years previous to the year 1816, much discontent had arisen in the commercial world, especially in the northern districts of England, owing to the extravagant charges and

general inefficiency of the navigable canal service as a means of transport. The canal proprietors, possessing a seemingly secure monopoly, had become arrogant and careless, or, it may be, unobservant of the growing requirements of trade. In the coal districts of Durham an extensive field was that situated a short distance north-west of Darlington, from whence coals were carried to Stockton, a place in communication with the sea, near the mouth of the Tees, and in this district the difficulties of transport had long been seriously felt. The construction of a canal had been proposed, but, after long dispute between the proprietors of Darlington and the merchants of Stockton, had been laid aside. The Stockton merchants, adopting the motto *Meliora speramus*, convened a public meeting to discuss what could be done, and a special committee was appointed to investigate the relative advantages of a canal or a tramway; still, nothing was effected; but the friends of some form of tramroad gradually gained the ascendant. Their proposals were modestly limited to a timber road, over which the traffic could be drawn either by horses or by ropes attached to the winding gear of stationary engines, and it was estimated that one horse could lead downwards from Darlington to Stockton ten tons of coal, and in returning about four tons of load, exclusive of the weight of the vehicles. No idea of conveying passengers was dreamt of.

A company was at length formed towards the end of the year 1816, and George Stephenson, who had been engaged on the preliminary surveys, was appointed engineer to the proposed line of tramway, or railway, and lost no time in urging upon the promoters the employment of iron rails in the place of wood. The raising of the requisite capital was only effected with extreme difficulty, principally through the subscriptions and exertions of the wealthy Quaker families of the neighbourhood. George Stephenson strove hard to impregnate the directors of the project with his own sanguine views as to the certain success and economy of steam locomotion, but the merchants and leading men of the district regarded his proposals with suspicion and ridicule, and persistently closed their purses. The capital, however, was at length raised, and the company went to Parliament, not indeed with the declared

intention of employing locomotives for the work of transport, but desiring only powers to provide 'for the making and maintaining of the tramroads, and for the passage thereon of wagons and other carriages by men and horses or *otherwise*.'

So great was the opposition that on three occasions the bill was negatived, and it was not eventually passed until the year 1821. On Tuesday, the 27th of September 1825, the Stockton and Darlington Railway was formally opened.

The most influential friends and advocates of this comparatively insignificant line of railway, which practically solved the great question of improved transport, were the Quaker family of Pease. One day in 1821 George Stephenson had a momentous interview with Mr. Edward Pease; induced him to visit Killingworth, where he could see for himself what a locomotive working on iron rails could do, and from that hour it was mutually decided by these two strong and energetic men that every nerve should be strained to obtain powers to work the traffic of the Stockton and Darlington line by steam locomotives. Fifty years later, on the occasion of the jubilee celebration of the Stockton and Darlington Railway in 1875, Mr. Henry Pease remarked, that it was surprising that the world should have been so many thousand years old 'before it was thoroughly known to what extent two simple parallel bars, laid at a given distance apart, would facilitate the intercourse of mankind.' He detailed in an amusing speech some of the early struggles and difficulties of the project. How one of its opponents had said, 'It is folly; you will never get your wagons to travel on the railway.' And another, 'I am sorry to find the intelligent people of the North gone mad on the subject of railways,' or 'It is all very well to spend money, it will do some good, but I will *eat* all the coals your steam-railroads will carry.' 'He did not live,' said Mr. Henry Pease, 'until the year 1874 when 127 millions of tons of coal were carried by railway, and I hope he had many good dinners on more digestible materials.'

At the opening of the line in 1825, in the presence of a great concourse of people, a train was formed, weighing 80 tons, consisting of one of George Stephenson's engines, 'No. 1,' driven by that able engineer himself, six wagons laden with

coals and flour, a covered 'coach' containing directors and proprietors, *twenty-one coal-wagons fitted up for passengers*, and filled by a promiscuous crowd, and lastly, six more loaded coal-wagons. This train, gaily decorated, started off with a horseman carrying a flag at its head. Crowds of people stood along the line, or ran on foot after the train, and gentlemen on horseback galloped across the fields to keep up with it. The speed was gradually increased to 10 miles an hour. At a favourable part of the road Stephenson determined to try the powers of his engine, he called upon the horseman with the flag to get out of the way, put on steam, and now 12 miles an hour, then 15 miles an hour were attained, and the runners of foot and the gentlemen on horseback were soon left far behind. 'When the train reached Darlington it was found that 450 passengers occupied the wagons, and that the load of men, coals, and merchandise amounted to about 90 tons.'[1]

The subsequent results of the opening of the Stockton and Darlington Railway were surprising in every way, both to the proprietors and to the public. It had not been intended to employ the line for the conveyance of passengers; but the demand for carriage became so great that the company was soon induced to provide the necessary accommodation. In October 1825, it was announced that the company's 'coach' called the 'Experiment' would run from Darlington to Stockton and back, every day except Sunday, making one journey each way per day. Each passenger was allowed to travel and take one package not exceeding 14lbs. in weight, at a fare of one shilling.

George Stephenson's interesting engine, 'No. 1,' which had cost the modest sum of £500 only, was before long supplemented by other improved and stronger engines, and the roadway itself was quickly brought into better order. As the traffic increased a double line was laid, and trains weighing up to 92 tons were run daily at 5 miles an hour. The rate for the carriage of merchandise per ton was lowered from 5d. to $\frac{1}{5}$th of a penny per mile. The cost of the carriage of minerals dropped from 7d. to $1\frac{1}{2}$d. per ton per mile, and the price of coals for shipment fell from 18 shillings to 8 shillings and six-

[1] *Our Iron Roads*, by Frederic S. Williams, London, 1888.

pence per ton. As a consequence, the export trade rapidly increased, and the company's shares rose to £40 premium each, 'with plenty of buyers, but no sellers.'

The small Stockton and Darlington Railway was constructed and carried through by a body of energetic local capitalists; but the first line made by capital raised in the public market and for the public benefit—and which in a more special manner marks the birth of the railway system of England and of the world—was that between Liverpool and Manchester. It was in the preliminary struggles of this railway, from its first inception to its final successful accomplishment, that the decisive battle between the new system of locomotion and the united forces of ignorance, prejudice, and avarice, was fought out and won; and it was this decisive victory that threw open the doors of public enterprise, and inaugurated the modern era of railways.

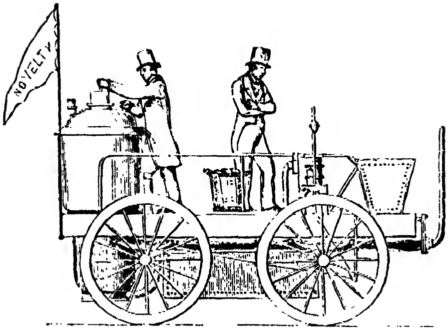
To recount the absurdities and extravagances, the ignorance, narrow-mindedness, and prejudice, displayed in this great encounter would probably raise a smile; whilst to picture the rapaciousness and greed aroused by alarmed self-interest, or by calculated avarice, would excite indignation and disgust. The interested reader will find the minutest particulars duly recorded in Dr. Smiles' *Lives of the Stephensons*. Early alive to the serious defects of transport and the dawning of a new era, the merchants of Liverpool in the year 1821 formed themselves into a committee, drew up a scheme, and established a company for the construction of a tramroad or line of iron rails between Liverpool and Manchester, wisely leaving open, as too contentious and combustible a question, the motive-power to be employed. So great, nevertheless, was the alarmed opposition of ignorance and vested interests, that it was only by stealth, by many ingenious stratagems—in the darkness of the night—or by actual armed force, that the first surveys could be made.

It was not until the end of four years, viz., in April 1825, that the first Parliamentary Bill, after a desperate struggle in committee with canal proprietors and landowners, extending over 38 days, was at length 'put and *negatived*' amidst the frantic cheers of its opponents. Nothing daunted, the projectors carried out fresh surveys, appeasing some of the most

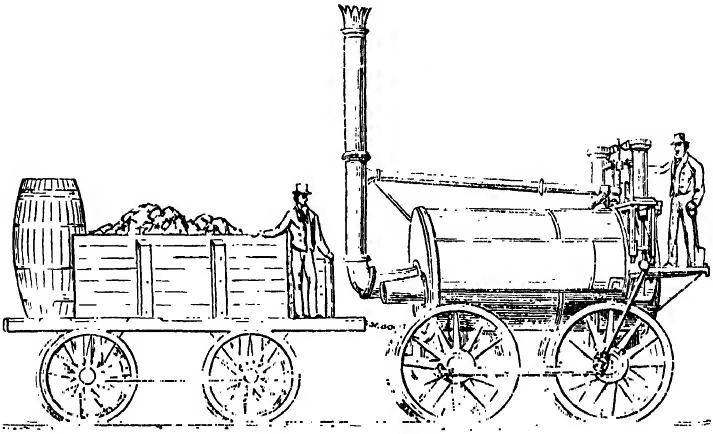
powerful opposition, and made a renewed application to Parliament in the ensuing year, when the third reading of the bill was at last carried by a majority of 88 to 41, at a cost to the company of £27,000. George Stephenson was at once appointed principal engineer, at a salary of £1000 a year. The works were vigorously prosecuted, and the line, in spite of many severe and unprecedented difficulties, was opened for public traffic on the 15th September 1830.

The question of motive-power to be employed on the new railway was virtually decided by the company's selection of their chief engineer. George Stephenson, assisted by his able son, had devoted himself now for many years to the perfecting of the locomotive-engine, and so numerous were the improvements he had devised and introduced, that the superiority of the locomotive for purposes of traction over fixed engines was now scarcely disputable. In the early part of the year 1829, the directors of the Liverpool and Manchester Railway appointed a committee of experts to inquire into the relative merits of locomotives and stationary engines, and, as the final result of the recommendations of this committee—who had visited the tramroad systems of the North of England, and had thoroughly investigated the different methods of motive power there employed—it was decided to publicly offer a premium of £500 for the best locomotive that might be brought forward by manufacturers, to compete under certain fixed regulations, the principal of which were:—That the engines should consume their own smoke; that if they weighed 6 tons they should be capable of drawing a train of 20 tons weight, including tender, at a speed of 10 miles an hour on a level railway; that each engine should have two safety-valves—one beyond the control of the driver; and that the height of the engines, including chimney, should not exceed 15 feet. Lastly, it was stipulated that the price of the engine was not to be more than £550.

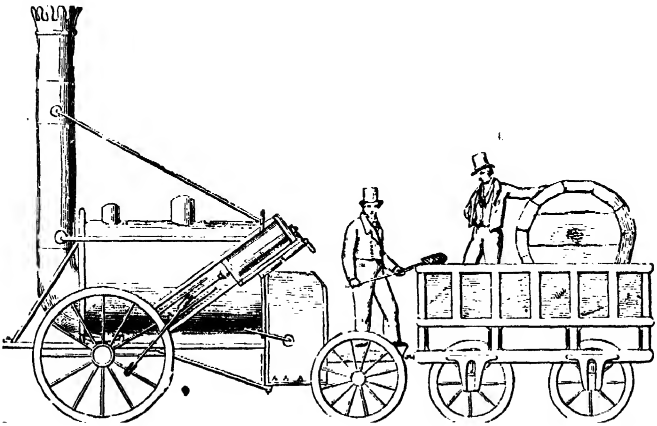
Only three locomotives entered the lists, viz., the 'Novelty,' by Messrs. Braithwaite & Ericson; the 'Sans Pareil,' by Mr. T. Hackworth; and the 'Rocket,' by Mr. George Stephenson. It was well understood that the prize of the competition was in reality the construction for the company of its entire stock



THE NOVELTY.



THE SANS PAREIL.



THE ROCKET.

of engines, and each competitor had strained every nerve to ensure the success of his machine. The merits of the respective engines were to be decided by the directors, assisted by three selected experts. On the day appointed for the trial, a level section of line about 1½ miles long was marked off, over which each engine in turn had to travel backwards and forwards ten times, making a total 'run' of 30 miles. The 'Novelty' succeeded only in passing twice over the distance, when the joints of the boiler gave way. The 'Sans Pareil,' on examination, was found not to be in strict accordance with the conditions; but it was decided that a trial of it might be made. After passing over the measured course eight times, the pump that supplied the boiler failed, and ended the experiment. The 'Rocket,' with a load of 17 tons attached, twice performed the distance of 30 miles; the first time in two hours and a quarter, and the second in two hours and seven minutes. The maximum speed attained by it was estimated at 30 miles an hour, and the average speed was about 14.

The great superiority of this engine over every other that had hitherto been made was due:—First, to the introduction by George Stephenson of a tubular form of boiler, consisting of an arrangement of tubes passing through the water-space, by which a very large heating surface was provided; and secondly, to the admirable contrivance of the 'steam-blast,' which directed the waste steam, after performing its main work in the cylinders, into the chimney of the engine, thus creating and maintaining during the whole time of working, a powerful draught, which secured a more rapid combustion of the fuel in the furnace, and generation of steam in the boiler. The success of the 'Rocket' was complete, and George Stephenson was appointed to build the engines for the company, which he continued successfully to do up to the time of his death in 1848.

The 'Sans Pareil,' although beaten in consequence of a trifling accident in this particular trial, was, nevertheless, a very remarkable engine, and probably but little inferior to the 'Rocket,' notwithstanding that the latter contained the germ of those improvements which afterwards guaranteed the success of the locomotive engine.

The 'Sans Pareil' for many years after the trial did a great deal of excellent work on the 'Bolton and Kenyon Junction Railway,' running as much as 120 miles a day for years.

The successful working of the Liverpool and Manchester Railway led to the immediate construction of the line between London and Birmingham—the parent of the modern 'London and North-Western' system, and let loose a flood of railway enterprise throughout the country, until the present network of railways was gradually built up. It must not be supposed, however, that the early lines of which we have been speaking were in any way comparable with the comfortable and well-equipped railways of the present day. The roads were hard, rough, and uneven, owing to the employment of unyielding stone blocks, instead of the elastic timber and other sleepers now used, and to the lightness of the rails and fastenings. Instead of the luxurious carriages of present railways, passengers had to ride in what were little better than open trucks, exposed to the inclemency of the weather, from which, as we may read, they occasionally overbalanced themselves and fell out, whilst the trains were in motion, or the roughest possible kinds of covered 'coaches' were provided for the higher class of passengers. The station accommodation was of the scantiest kind, and the trains, running at an average speed but little superior to the fastest coaches then on the roads, were few and far between, and started or arrived at their destinations at all sorts of uncertain and irregular intervals. But from the year 1830, every year, and almost every month, witnessed some improvement, either in the road, in the carriages, the engines, or in the service of the railway, until the comforts and security of modern travelling were gradually attained. Nor must it be imagined that the ultimate term in railway improvements has even yet been approached.

In concluding this rapid sketch of the rise of the railway system in England, we cannot refrain from quoting a few words of a speech delivered by George Stephenson in the year 1844, on the occasion of the opening of the 'Newcastle and Darlington Railway,' containing, as it does, so many interesting references to his career. 'Yes,' he said, 'Lord Ravensworth and the Killingworth owners were the first parties that

would intrust me with money to make a locomotive engine. That engine was made 32 years ago. I said to my friends that there was no limit to the speed of an engine, provided the works could be made to stand. In this respect great perfection has been reached, and in consequence a very high velocity has been obtained. In what has been done under my management, the merit is only in part my own. I have been most ably assisted and seconded by my son. In the earlier part of my career, and when he was a little boy, I saw how deficient I was in education, and made up my mind that he should not labour under the same defect, but that I would put him to a good school, and give him a liberal training. I was, however, a poor man; and how do you think I managed? I betook myself to mending my neighbours' clocks and watches at night, after my daily labour was done, and thus I procured the means of educating my son. He became my assistant and my companion. He got an appointment as under reviewer, and at night we worked together at our engineering. I got leave to go to Killingworth to lay down a railway at Hetton, and next to Darlington; and after that I went to Liverpool to plan a line to Manchester. I there pledged myself to attain a speed of 10 miles an hour. I said I had no doubt the locomotive might be made to go much faster; but we had better be moderate in the beginning. The directors said I was quite right; for if when they went to Parliament I talked of going at a greater speed than 10 miles an hour, I would put a cross on the concern. It was not an easy task for me to keep the engine down to 10 miles an hour; but it must be done, and I did my best. I had to place myself in that most unpleasant of all positions, the witness-box of a Parliamentary committee. I could not find words to satisfy either the committee or myself; some one inquired if I were a foreigner, and another hinted that I was mad. I put up with every rebuff, and went on with my plans, determined not to be put down. Assistance gradually increased —improvements were made—and to-day, a train which started from London in the morning, has brought me in the afternoon to my native soil, and enabled me to take my place in this room, and see around me many faces which I have great pleasure in looking upon.'

CHAPTER II

PRINCIPLES OF CONSTRUCTION

Principles of construction of railways—Preliminary—Canals and railroads—The 'idea' of a railway—Expense of reduction to practical form—Embankments—Viaducts and cuttings—Land purchase and compensations—Opinions of engineers in early days of English railways—Choice of route and deviations—Survey and levels—'Formation' and grading lines—Plans and sections—Acquisition of land—Legal regulation of powers of railway promoters—Compensation for damage or injury to property—Parliamentary plans and sections—Alterations—Legal knowledge essential to the Engineer—The Board of Trade—Powers—Maxima and minima dimensions—Superiority of India in uniformity—Important regulations of the Board of Trade.

Preliminar

To understand rightly the principles involved in the application of railways to the purposes of land locomotion, it is necessary to consider for a moment what are the natural resistances which obstruct freedom of movement—and especially rapidity of movement—of any kind. These are three in number, viz., Terrestrial attraction, resistance of the atmosphere, and *friction*. It is beyond any human effort to remove either the first or second, but the last is capable of being so largely reduced as to become practically non-existent. It is therefore principally by the application of human ingenuity to the reduction of the resistance of friction, that the rapidity of motion attained on a line of railway has been rendered possible. On any form of common road the resistance offered by friction to the rapid draft of heavy loads can only be reduced to a certain limit, which is very soon reached. Moreover, the expense of effecting the reduction is incurred over a maximum surface. Hence, before any further advance can be made, something altogether new must be devised. In the history of locomotion this something new first took the form of a yielding and mobile *water*-road, in place of a hard macadamised surface. By the

introduction of navigable canals the resistance of friction to the motion of heavy bodies was greatly reduced, and an important step in advance was made; but the most notable, the most convenient, and on the whole the most economical solution of the problem, was soon found in the tramway, and its rapid subsequent development into the true railway.

The 'idea' of a railway is to furnish two parallel lines of hard, smooth, and unchanging surfaces for wheels to roll upon—no expenditure, so far as concerns reduction of surface friction, being required on any other part of the road, except on those two very narrow surfaces immediately under the rim of the wheels. It is a very simple idea!—but is one of the last that took possession of the human mind—once seized, however, mechanical difficulties only remained, which were soon surmounted, and, accordingly, two lines of strong straight bars of iron—2½ to 3 inches wide, and 4 to 6 inches deep, laid and firmly supported at a little distance above the general ground surface—were placed at an even distance apart, so as to suit the width of the vehicles; the separate lengths of iron bar were neatly joined together, end to end, and spiked or secured to blocks of wood or stone at short intervals; and, lo! the simple idea was at once embodied in the form of a railway, or iron road, which immediately opened an economical pathway for the introduction of steam, or any other source of power that man might wish to employ for purposes of traction and locomotion.

Simple, however, as the idea of a railway is, its realisation in practical form is often attended with prodigious expense. The natural irregularities of the earth's surface must, in one manner or another, be reduced or removed. Low parts, and often deep valleys, must be filled up by embankments or viaducts. High parts must be cut through by cuttings; or, if the height is too great, must be bored through by tunnelling. Rivers and watercourses, however large or small, must be crossed by bridges—all with the one object of reducing the whole route to one uniform and moderately level surface, so as to reduce friction and prevent loss of tractive power by operating against the action of gravity. The land also on which the railway is constructed has to be purchased, often at great cost, and compensation paid for interference with the

rights of property. The great strength and solidity required in all constructions connected with the road surface of railways, in order to withstand the impact of enormously heavy loads moving at those high velocities which the power of steam and the smoothness and evenness of the rails render possible, is the cause of great outlay, and imposes on the railway engineer works and operations of the greatest magnitude and responsibility.

The general principles of the construction and working of a line of railway are virtually the same in all parts of the world. We will therefore, in the first instance, indicate a few of these general principles, irrespectively of country or locality, so as to familiarise the reader with the various nature and extent of the principal operations undertaken by the railway engineer. We will then briefly glance at the introduction of railways into India, and note some of the special peculiarities of their construction and working in that country, illustrating a few of the more remarkable railway structures which have been carried out, and supplying the reader with such information as to the working results of Indian railways as may be of general interest.

In the early days of English railways, the decision as to the best route for any proposed line was often very summarily disposed of. Given the chief termini, it was said, 'make your line as straight and direct as possible from one point to the other; disregard the smaller centres, because when once the line is open people and trade will flock to it as bees to a honey-pot, and in a few years it will run through a rich and populous district, which it has itself created. If necessary, feeders and branches can be made from any towns of importance, but keep to the shortest and most direct route for your main line. It is the through traffic that will *pay*; the local traffic, which is of less importance, will create itself.' These views, however, were soon modified. Contrary to what was supposed, it was found that the short local traffic paid as well, or even better, than the long through traffic, and that it was more economical to allow extra length to a main line rather than to multiply branches.

The selection of the exact route to be taken by any proposed

line of railway is often one requiring very great skill and judgment, so as fairly to balance economy in construction with commercial advantages and public convenience. Mr. Robert Stephenson, whilst engaged in settling the precise demarcation of the London and Birmingham Railway, is said to have walked over the whole 113 miles of distance between these towns no less than twenty times. After the position of all obligatory points has been determined, the first studies for a line of railway usually result in the alternative of two or three possible routes. Trial shafts and borings are then sunk in order to ascertain the geological formation of the country to be traversed; closer trial levels are run, and approximate sections are made, so as to exhibit on paper the main inequalities of the ground, and to indicate the probable mass of the heavy embankments or cuttings required. The consideration of all merely local deviations, necessary for avoiding expensive properties in the country, if not in the neighbourhood of cities and towns, is for the present postponed; but the crossing-places of the principal rivers and streams are fixed, so that they may be as economically situated as possible. When all the data necessary for forming an accurate judgment has been collected, the engineer responsible for the project balances the evidence in favour of or against the various trial routes, and proceeds to mark out on the ground the exact line which he, or the promoters advised by him, have finally decided upon.

This route must now be very carefully adjusted in detail and then surveyed, and a line of close levels must be taken along the centre line—which has been deeply nicked or scored on the ground—on stout pegs driven at intervals of, say, every chain's length. The survey will determine by actual measurement the exact form and dimensions of all the natural or artificial features of the ground to be occupied by the railway, and for some distance beyond it on either side, so that these features can be represented graphically to scale on paper. The levels taken will closely show all the various elevations and depressions of the ground surface above some fixed point or 'datum,' usually the mean level of the sea, and when these levels are plotted in continuous order on a roll of paper, and the surface of the ground is traced through them, the engineer will be enabled to

draw on the 'section' thus formed what are called the 'formation' or 'grading' lines—that is, those lines representing the future surface levels of the railway. Where land for depositing soil, or for excavating material, is very valuable, he will endeavour, as far as possible in drawing these lines, to reduce the necessity of its acquisition by balancing the total amount of cuttings and embankments over given lengths of the section, so that the material from the former will, as nearly as possible, serve to build up the latter; but the high or low level of the formation lines will be principally determined with reference to the amount of earthworks involved, and the necessity for keeping the rate of inclination within that maximum limit which it has been deemed expedient on various grounds to adopt.

This very important matter of 'grading' the line having been finally determined, the engineer proceeds to plan out and design all the works and structures required from one end to the other of the railway, whether large viaducts, smaller bridges, tunnels, or other necessary works, and the exact position, main dimensions, and serial number of all such structures will be carefully marked on the plans and sections. He will determine station accommodation of all kinds, whether for the service of the railway itself or for the public convenience, and will design, or provide for, all matters appertaining to the detailed working of the line, such as signals, telegraphs, engine accommodation, workshops, housing of staff, and all the thousand minor requirements of a working railway. In the meantime the quantities and value of all items of labour and materials that will enter into the construction of any and every part of the line are taken out and scheduled in regular order, until one general 'estimate' is framed, which, according to the skill and experience of the engineer, will represent, with greater or less approximation, the true initial cost to the proprietors of the proposed works.

The construction of a line of railway necessitates the acquisition of a continuous strip of land to be assigned for its exclusive use and occupation; a strip, moreover, which in the majority of cases inconveniently disconnects and severs from free intercommunication the adjoining lands on either side of it. There are consequently but few cases where a railway can be con-

structed without a more or less serious interference with private rights, or without subjecting the owners of adjoining properties to some degree of loss or inconvenience. Hence in all civilised countries it has been found necessary to safeguard the legitimate rights of property, and to regulate and define the powers to be granted to railway promoters by means of legislative enactments.

These enactments proceed on the assumption that the construction of any line of railway is for the public advantage, and—this assumption being proved—that the particular rights of private owners should give way to the general good of the community. In accordance with the provisions of the various railway enactments, companies may obtain legal powers to construct, work, and maintain a line of railway, and authority to acquire compulsorily such lands and other private property, as may be shown necessary for the occupation of the line, stations, or approaches, but these powers and privileges are only conferred under most stringent regulations, framed to protect the rights of private persons which may be interfered with by the construction of the line, and to ensure them adequate compensation. Nor is this compensation only a pecuniary one. Owners are empowered to require from the railway company the construction of all such reasonable works and conveniences which it can be shown will neutralise, or mitigate, the damage or injury sustained.

Before legal powers are granted, a railway company has to satisfy Parliament—or other corresponding Government authority—that the construction of the contemplated railway will really be a benefit to the public, and that it will be constructed and worked in such a manner as to be safe and efficient, both as regards the general public, and the adjoining proprietors or occupiers.

The engineer of a railway has, therefore, in the first place, to prepare for submission to Parliament, accurate land plans and books of reference, showing exactly what lands the railway company propose to acquire, within certain permissible limits of deviation. He has, in addition, to submit sections of the proposed railway, showing all gradients, curves, cuttings, embankments, tunnels, viaducts, bridges, or other works, and in order

to ensure perfect uniformity, all these plans, sections, and documents of every kind are required to be prepared and submitted in one and the same rigidly specified manner, whether with regard to scale of drawings, or in every other particular, instructions for which are laid down in minute detail in the 'standing orders' of Parliament, which must be precisely adhered to, on pain of absolute rejection of any application for powers. Moreover, when powers are at length obtained, no subsequent alterations, whether of route, gauge, gradient, curves, or structures of any kind are admissible, except within the limits of stringent regulations expressly formulated. So greatly, in short, are railway and other engineering works governed and regulated by special legislative enactments, that a very considerable amount of legal knowledge is one of the first necessities of the professional engineer in almost every country.

In England, on the completion of a line of railway, it is necessary that it be found in accordance with the special requirements of the 'Board of Trade,' and if on inspection by the officers appointed by this Board it is found otherwise, the opening of the railway for passenger traffic may be postponed from month to month until such requirements are complied with, or if the line be opened for passengers without the required permission, a legal penalty of £20 a day for every day during which the line remains open without permission may be enforced under the provisions of an Act of Parliament. In England, therefore, if a railway company prefers the alternative of paying the sum of £20 a day, a new passenger line may apparently be opened without any inspection whatever, and the Board of Trade appears to have no power absolutely to order the closing of a line from any cause.

After a line has once been opened the Board of Trade has no further powers, either of inspection, or to order any improvements, or to interfere in any way with the working of a line—except by making suggestions or recommendations—unless additional new works are undertaken, in which case these additions are subject to inspection, and the alteration of such of the old works as are in connection with, and dependent on them, may then be enforced.

According to the present state of English procedure in this particular, it would appear that the Board of Trade may practically enforce on new lines all the latest improvements and best precautions warranted by the most recent scientific advancement, but at the same time an *old* line—on which in course of years an enormous traffic has grown up, far surpassing that likely to be attained on any new line, at least until such time as the new precautions enforced have themselves been superseded—may continue to be worked in the old manner without the use of the new precautions or improvements. In practice, however, although the anomaly in legal powers is great, the evil is of less importance than might be supposed, inasmuch as in nearly all cases railway companies are so strongly interested in the safe working of their lines, as to be willing eagerly to adopt every possible new precaution and improvement that presents itself as practically valuable. The deficiency in the legal powers of the Board of Trade are perhaps most strongly felt in the case of old lines on which—owing to various causes—the older dimensions of fixed structures in relation to changes in rolling stock have in course of time brought about a more or less dangerous state of things, which, as they cannot be altered without incurring heavy expense, are exceedingly liable to be unattended to until some serious accident has resulted. An absolute and rigid uniformity in the relative maxima and minima dimensions of contiguous structures and rolling stock, on every line of a given gauge, is a matter which was greatly neglected in the early days of railroads in England. In India, on the other hand—as we shall see later—this important particular has from the first been carefully attended to, and Indian railways, so far as uniformity in standard dimensions are concerned, are probably the most perfect in the world.

The regulations of the Board of Trade, with respect to the requirements necessary on the opening of new lines, are subject to additions or alterations from time to time, and are issued in circular form for the guidance of its own officers, and for the information of the engineers engaged in the construction of new lines of railway. The inspecting officers have the power of modifying these regulations to meet particular cases, but in

the main the certificate of the Board of Trade will not be given unless the regulations are strictly observed.

The following is a memorandum of some of the more important of these regulations to which English railway companies opening new lines are required to conform, and which—so far as applicable—have also been adopted on all Indian railways—

1. The requisite apparatus to be provided at the period of inspection, for ensuring an adequate interval of space between following trains.

2. Home signals and distant signals for each direction to be supplied at stations and junctions, with extra signals for such sidings as are used either for the arrival or for the departure of trains.

3. The levers and handles of points and signals to be brought close together into the position most convenient for the person working them, and to be interlocked. The points to be provided with double connecting-rods. The levers of the points to be sufficiently long to enable the pointsman to work them without risk or inconvenience, and not to be placed on the ground between the lines of rails. All signals which are worked by wire should be so weighted as to fly to 'danger' on the fracture of the wire.

4. Facing points to be avoided as far as possible.

5. It being necessary that a uniform system of signals should be adopted on all railways, the semaphore arms should, at stations and junctions where there is more than one on one side of a post, be made in future to apply, the first or upper arm to the line on the left, the second arm to the line next in order from the left, and so on. In the case of sidings a low and short arm, distinct from the arm or arms for the passenger lines, may be employed. Clocks should be placed in conspicuous positions for the use of the signalmen.

6. The signal-handles and the levers of the points should be brought together under cover upon a properly constructed stage, with glass sides enclosing the apparatus. They should be so arranged that while the signals are at danger the points shall be free to move; that a signalman shall be unable to lower a signal for the approach of a train until after he has set the points in a proper direction for it to pass: that it shall not be possible for him to exhibit at the same moment any two signals that can lead to a collision between two trains; and that, after having lowered

his signals to allow a train to pass, he shall not be able to move his points so as to cause an accident, or to admit of a collision between any two trains. The facing points should be provided with apparatus which will ensure the points being in their proper positions before the signals are lowered, and which will prevent the signalman from shifting the points whilst a train is passing them. Every signalman should be able to see the arms and lamps of his home, as well as his distant signals, and the working of his points. The fixed lights in the signal-cabins should be screened off, so as not to be mistakable during fogs for the signals exhibited to control the running of trains.

7. The junctions between passenger lines and any sidings should be protected by a home signal and a distant signal in each direction.

8. When a junction is situated near to a passenger station, or is connected with goods or mineral sidings, the platforms and sidings should be so arranged as to prevent as far as possible any necessity for shunting over the junction.

9. When two single lines meet, the junction should, in ordinary cases, be formed as a double-line junction.

10. The lines of railway leading to the passenger platforms to be so arranged that the engines shall always be in front of the passenger trains as they arrive at and depart from the station.

11. Platforms to be continuous, and the descent at the ends to be by ramps, and not by steps. Pillars or columns for the support of roofs, or other fixed works, not to be nearer to the edge of the platform than 6 feet.

12. No station to be constructed on a steeper gradient than 1 in 260. When the gradient at a station is unavoidably steeper, and the line is double, and when danger is to be apprehended from vehicles running back, a catch siding, with points weighted for the siding, should be provided farther down the incline than the passenger platform and goods yard, to intercept runaway vehicles. When the line is single, a second line should be laid down, a second platform constructed, and a catch siding similarly provided.

13. The upper surfaces of the wooden platforms, of bridges, and viaducts, should be protected from fire.

14. No standing work (other than a passenger platform) should be nearer to the side of the widest carriage in use on the line than 2 feet 4 inches at any point between the level of 2 feet 6 inches above the rails, and the level of the upper parts of the highest carriage doors. This applies to all arches, abutments, piers, sup-

ports, girders, tunnels, bridges, roofs, walls, posts, tanks, signals, fences, and other works, and to all projections at the side of a railway constructed to any gauge.

15. The intervals between adjacent lines of rails, or between lines of rails and sidings, should not be less than 6 feet.

16. At all level-crossings of turnpike and public roads the gates should be so constructed as to close across the railway, as well as across the road, at each side of the crossing. They should not be capable of being opened at the same time for the road and the railway. Wooden gates are considered preferable to iron gates for closing across the railway.

17. The fixed signals attached to the gates at the level-crossings should be placed in convenient positions for being seen along the railway, as well as along the road. When a level crossing is so situated that an approaching train cannot be seen from a sufficient distance, distant signals (which may both be worked by one lever) should be supplied.

18. Mile posts, and quarter and half mile posts, and gradient boards, should be provided along the road.

19. Tunnels should in all cases be constructed with recesses for the escape of platelayers.

20. Viaducts of timber and iron should be provided with man-holes and other facilities for inspection, also with hand-rails and with projecting platforms for the protection and escape of the platelayers.

Numerous regulations as to the strength and details of construction of works in iron are also laid down.

CHAPTER III

PRINCIPLES OF CONSTRUCTION

Formation of line—Turning the first sod—Commencement of practical construction—Temporary lines—Main divisions of work—Meaning of the term 'permanent way'—Construction of earthworks—Gradients—Curves—Elevation of outer rail—Steep gradients and sharp curves on mountain railways—A Welsh engine-driver—Construction of a cutting—Width of formation—Principal difficulties met with in cuttings—Importance of drainage of earthworks—Tunnels and tunnelling—The formation of embankments—Settlement—Viaducts, bridges, and culverts, size of openings—Magnitude of some examples of European and American railway structures—Tunnels and railway bridges—Service bridges and level crossings—Fencing—Indian and American practice.

'Formation' of the line. The actual commencement of the works on an important length of new railway, is generally considered a fitting occasion for some public display of special satisfaction and rejoicing on the part of all friends and promoters of the undertaking who have successfully pioneered the project through its difficult and dangerous periods of incubation and parliamentary contest, and the 'cutting of the first sod' is often celebrated with much time-honoured ceremony, followed by that liberal consumption of 'good cheer,' without which no true Anglo-Saxon can regard any undertaking as properly inaugurated. The interest of some distinguished personage of high degree is enlisted, or the services of the highest available local magnate are retained. The directors and their friends and guests—probably including all the leading nobility and gentry of the neighbourhood—duly assemble at time and place appointed. A resplendent wheelbarrow and spade of polished wood and shining silver is formally presented by the chairman to the distinguished personage, or local magnate, as the case may be, who is earnestly invited in a flattering speech to convert him-

self—ceremonially—into a navvy for a short space. Graciously assenting, the distinguished personage divests himself of his outer garment, and if very enthusiastic rolls up his shirt sleeves, and plunges the elegant and costly spade into the virgin turf; the wheelbarrow is duly filled, is rolled off along the appointed plank-way, and is gravely overturned amidst the cheers of the assembly. The magnate retains the valuable implements as a worthy trophy of the occasion, and the party adjourn to the more substantial features of the celebration. The date of commencement of the new railway is thus for ever marked in the public annals of the country.

The practical construction of the new line, by the contractor or other agency employed, is always commenced at those parts of the route where the greatest quantity of work has to be done, and the operations throughout are taken up in such order that the whole of the works, or those on a certain defined portion, may be completed simultaneously. The lighter portions of the road connecting the heaviest cuttings and embankments are, however, at once brought to proper level, and temporary lines of rails are laid down to facilitate the transport of material from the former to the latter. Labour and working plant is collected at the sites of all the larger viaducts, bridges, tunnels, or other heavy works, and arrangements for getting in the deepest and most troublesome bridge or other foundations are rapidly pushed forward, until in a very short time the greater part of the route of the new line presents a busy scene of life and activity.

The works on a line of railway are apportioned into three main divisions, respectively called, the 'formation' of the line, the 'ballast and permanent way,' and 'station buildings and machinery.' The 'formation' level of a railway is the finished top of the line of embankments, the bottom of cuttings or tunnels, and the floor level of viaducts or bridges. Above this level is placed the 'ballast,' and in and on the ballast is laid the 'permanent way,' consisting of the sleepers, chairs, rails, fastenings, points, and crossings, in short, all those materials which form the actual road on which the engines and vehicles run. The term 'permanent' way serves to distinguish the completed road from the 'temporary' lines of way used by

contractors or others merely for carrying materials or facilitating construction. It is obvious that the main mass of labour and materials is comprised in the first of these three divisions, viz., the 'formation' of the railway, and of this division 'earthworks' form a very large item (the removal of all material, whether earth, gravel, or rock, being included in this term). In a vertical direction the construction of the 'earthworks' involves the formation of that uniform top surface which has been planned by the engineer to take the place of the irregular and uneven natural surface of the ground. This uniform surface will sometimes lie above the natural ground; sometimes below it, necessitating here an embankment or viaduct, there a cutting or tunnel. When completed, it will either be a *level* surface, or will have a certain degree of regular slope called a 'gradient.'

The traveller by railway by observing and reading the 'gradient boards' affixed at intervals along the side of the line can always discover whether he is going up hill or down hill, or along a level. Thus he may see an arm projecting forwards from a low post, in the direction he is travelling, having a slightly upward angle, and bearing, perhaps, a sign 1—350, meaning that the surface of the road is now rising uniformly at the rate of one foot in every 350 feet of distance. Presently he will arrive at another post, with arm projecting downwards in a reverse or backward direction, and marked in the same terms, but on the other or forward side of the post he will see another arm in a horizontal position, indicating that beginning from that point the road is now horizontal or level, and so on at every place where the slope of the artificial surface or 'gradient' changes he will find it duly recorded by the posts and arms. The object of these gradient posts is to inform the engine-driver of the nature and degree of the road inclination against him or in his favour.

Horizontally, or in plan, the construction of railway earthworks will always proceed in a straight line except at certain definite places where two straight lines will be joined together by a *curve* or curves. There are, therefore, two important matters to be carefully regarded by the engineer immediately engaged on the works, viz., the correct formation of the surface 'gradients,' and the accurate tracing and preserving the align-

ment of the various straight lengths and curves as exhibited on the plans. For a long time after the first introduction of railways it was held as the very first principle of construction that the running surface should be everywhere made as nearly level as possible—original outlay being held of secondary consideration as compared with the supposed subsequent economy of working. The original London and Birmingham Railway, and in some degree the Great Western, are examples of this mode of construction. On the former line no gradient exceeded 1 in 330, with the exception of the Camden Hill incline, which it was intended to work, and which for some years was actually worked, by a stationary engine.

It was conceded, however, after some experience had been gained, that a series of moderate undulations, or up-and-down gradients, although enormously cheapening original construction, do not result in any serious increase in working expenses; the power saved in the descending portions of the road compensating in great measure for the excess on the rising gradients. Moreover, the enormous improvements in the capabilities and power of modern locomotives, permits gradients to be now adopted which a few years ago would have been prohibitory, and have enabled engineers to carry lines of railway over districts which in earlier days would have been regarded as economically impassable.

In an ordinary plain country the total length of curves on a line of railway will generally be very small as compared with the total length of the straight portion, the average degree of curvature will also be very much less than in a hilly district. In the infancy of railways, curves, unless of very large radius—that is, of very gentle curvature—were regarded with very much alarm. Under Parliamentary standing orders the necessity for curves of less than a mile radius (5280 feet) was required to be separately inquired into. It was supposed that the resistance offered by curvature of the line would be exceedingly great, and that the tendency of trains travelling at high speeds to continue their motion in a straight line, instead of following the curved track, would cause them to leave the rails, and lead to inevitable disaster. Experiments, however, did not confirm these apprehensions. It was found that the resistance offered

by curves having a radius down to 2500 feet, or even less, was hardly appreciable at any practicable rate of speed. By slightly raising the level of the outer rail on curved portions of the line an inward inclination was given to the moving vehicles, which largely counteracted the centrifugal force tending to cause them to leave the rails—just as the body of a circus horse galloping round a ring will, in proportion to his speed, be strongly inclined inwards towards the centre of the curvature. The amount of elevation given to the outer rail is found by calculation, and is dependent on the radius of the curve, the gauge of the railway, and the maximum speed of the trains. This expedient, combined with the lateral play or side movement allowed to the coned wheels—which will be more specially referred to when we are speaking of the permanent way—imparts to the vehicles travelling on a curve a certain degree of natural tendency to move in a circle, just as a cone placed on its side will roll in a circular path, and thus the amount of resistance and danger of leaving the track was reduced to a minimum, and the employment of curves of much smaller radius than those formerly allowed was rendered possible.

It is obvious that there are some situations, such, for example, as the approach to a terminus, or to important stations, over which the starting or arriving trains will always be moving at a very low rate of speed—where much sharper curves may with safety be introduced, than on middle sections of the line, travelled over with great velocity. The danger of very sharp curves is moreover increased in proportion as the inclination or 'gradient' is also great. Nevertheless, in mountainous districts the combination of exceedingly steep gradients and very sharp curves is commonly obligatory, and such lines can be safely worked with special precautions as to limitations of speed, or by the help of auxiliary appliances, such, for instance, as the cogged rail employed on the Righi mountain, near Lucerne. On Alpine railways, and in many of the mountain lines in America, the extent and degree of curvature now safely worked over without the use of extraordinary appliances and at ordinary speeds, would startle the timid and inexperienced first projectors of railways. In many of the more hilly districts of Wales mineral and passenger lines of narrow gauge have been

carried in and out of the intricate valleys of the country in a manner truly surprising. The long trains sometimes double round on themselves in such a manner that passengers from a window in a foremost part of a train will see the hindermost portion pass by them, moving in a direction contrary to their own motion. Series of sharp double reverse curves impart such a snake-like and winding aspect to these trains as almost to warrant the bold hyperbole of a certain Welsh engine-driver, who is asserted to have said that, one dark night, when he was new to the road, he was pulled up by the tail danger-lights of his own train.

Having now given our readers some particulars of railway 'gradients' and 'curves,' we may return to the earthworks of our new line in course of construction. As soon as the temporary line of rails in those lighter portions of the road lying between the heaviest cuttings and embankments has been laid, so that the material from the one may be trained to the other, gangs of workmen attack the face of the hill through which the cutting is to be carried, and soon a narrow passage or 'gullet,' just wide enough to receive a row of tip-wagons is formed and projected into the body of the hill, and into this gullet the temporary line is prolonged. The 'stuff' from the walls of the gullet is showered into the wagons, now lying just alongside, and as soon as they are filled they are led away, or are allowed to run down by their own impetus, if the inclination of the road is favourable, to the 'tip' of the neighbouring embankment.

Near the embankment end of the temporary road the line forks into two or more lines, forming 'sidings,' and the wagons descending or led from the cutting are run into one or other of these, and are made to discharge themselves singly over the embankment 'tip,' or it may be simultaneously over the sides. In the meantime a train of empty wagons is hauled by horses or engine-power, or is allowed to run back to the cutting; is filled in its turn, and is again sent off and emptied at the embankment. By constantly repeating this process the 'gullet' of the cutting is daily carried farther and farther into the hill, and the head or 'tip' of the embankment is advanced farther and farther into the valley.

The 'formation' approaches on either side of a cutting, and

in the greater part of a cutting itself, are, in order to minimise excavation, nearly always on some gradient, either in one direction only, or in both directions. If there is an inclination in both directions there will generally be a small intervening length of *level*, situated somewhere about the middle of the cutting. In this very common state of matters work can conveniently proceed from both sides of the hill at the same time, and the two gullets are prolonged until they meet in the centre. As the gullet is gradually widened out the temporary rails are pushed over so as to bring the wagons close to the wall of earth, and soon there is room for a second line of rails, enabling *two* trains of wagons to be loaded up simultaneously. Before long the gullet—now of the full bottom width of the cutting, but with vertical, or nearly vertical, sides—will be carried right through the hill, and the work of forming the side slopes will be commenced. Lines of planks and trestles will be formed, along which the crowd of navvies trundle their wheelbarrows, and discharge the contents into the wagons, or if the amount of 'stuff' from the cutting is more than sufficient to form the neighbouring embankment, the surplus material has to be 'put to spoil.' In this case, if the cutting is very deep, 'runs' of planks are sometimes formed up the sloping sides, and the men and barrows are hauled up the inclined planes by ropes, worked by horses from the ground-level above, and the surplus material is deposited on land specially provided for it, clear of the cutting. If, on the other hand, the quantity of material furnished by the cutting is insufficient to complete the embankment, the balance will either be run from other cuttings situated farther away along the line, or it will be obtained from side-cuttings, sometimes called 'borrow-pits,' dug on separate land alongside the unfinished portion of the embankment. Cases will often occur, when the distance and cost of transporting material from a cutting to the site of the nearest embankment, or the small size of the banks and cuttings themselves will, in relation to the value of land, render it more economical to procure *all* the earth for a bank from side-cuttings, and to place *all* the material from a cutting to 'spoil.' Every case will be decided by the engineer according to considerations of expense and rapidity of execution.

The *width* of the earthworks on a line of railway on the top, or 'formation' level, will depend upon varying circumstances, such as the number of lines of way, the gauge of the railway, and the length of the sleepers. To allow ample space for side drains or ditches, the width is always greater in cuttings than on embankments, the extra width depending on the size and particular kind of side-drains necessitated by local conditions of soil and quantity of water to be drained away.

The principal difficulties met with in heavy cuttings are due to the nature and inclination of the strata cut through, the behaviour of the material under the influence of exposure to weather and the presence of springs. Some materials will not be secure from all danger of slipping at almost any angle of slope, and the heavy expense of retaining-walls may have to be resorted to. Other materials require very flat slopes and expensive drainage-works before stability can be secured. Alternate strata of sand and clay, or shale, are especially dangerous or troublesome, particularly if heavily inclined and full of water. Other materials stand firmly at slopes of $1\frac{1}{2}$ or 2 to 1. Hard clean rocky strata, although expensive to cut through in the first instance, are often the most econominal in the long run as the slope will stand almost vertical, imposing a smaller quantity of initial excavation, and little or no subsequent outlay.

The bottom or 'formation' level of cuttings is generally made with a fall towards each end, and side ditches, either excavated or constructed of masonry, are formed along the foot of the slopes, by means of which water is allowed to drain away. Catch-water drains, especially on sloping ground, will also be necessary along the summit level of cuttings to cut off flood water from the upper slope. *Water*, in fact, is the one great enemy of completed earthworks, and thorough and efficient drainage is everywhere imperative to prevent them from being slowly worn away and dissolved. No expense is spared by the judicious engineer in order to get rid as quickly as possible of all water from the neighbourhood of his earthworks.

The cost of cuttings increases in proportion to their depth, hence there is always a certain limit at which it becomes more economical to burrow, or tunnel underground, than to continue

the open cutting. This limit, although it will vary somewhat according to the nature of the material to be excavated, is in ordinary cases found to lie somewhere between 60 or 70 feet of depth. In very hilly or mountainous country—unless it so happens that a very great deal of material is required for high embankments, which cannot be obtained except from the cuttings —this economical depth is usually soon reached, and tunnelling will be resorted to with more or less frequency. Short tunnels commonly present little difficulty, and can be bored or 'driven' through a hill from end to end without intermediate shafts. Beyond a certain length, however, and in cases where the depth of the tunnel below the natural surface of the ground is moderate, it becomes economical to sink one or more shafts, or wells, along the centre line of the tunnel, from the bottom of which boring or driving the tunnel can be carried on in two directions. By this means the work is prosecuted with greater rapidity from more numerous points of departure.

Simple tunnelling through hard rocky materials is generally carried on by blasting, either by gunpowder, dynamite, or other explosive. A small opening or 'heading' is first pierced by the miners working in front, and others following them gradually enlarge the opening to the full section of the tunnel. In the softer kinds of material, however, the difficulty and expense of tunnelling is often greatly increased, especially if considerable quantities of water are met with. The whole of the sides and roof of the tunnel excavation as it advances will be shored up, or supported by temporary timber work, and a permanent lining of stone or brick masonry of a strength sufficient to withstand the pressure of the surrounding material will be necessary, every part of which will be set in durable cement, to prevent the percolation of water. Very heavy and expensive pumping operations may also be necessary.

In the formation of an embankment, the loose vegetable soil on its seat is first removed in order that a good and solid 'bottom' may be obtained for the load to be placed upon it, and all roots of trees, stumps, brushwood, and other matter which might by decay cause ultimate subsidence, are carefully cleared away. The earth, from the commencement, is deposited over the whole width of the intended bank, in order to avoid

the necessity of any subsequent lateral additions; always difficult to connect with the original mass. Wherever such additions are unavoidable the older work is cut into deep trenches, or steps, to prevent the newer work from slipping. The proper elevation and alignment of embankments is guaranteed by the previous erection of posts or brick pillars erected at convenient intervals along the centre line, and the correct level of the top of the finished earthwork is marked on these posts or pillars; but in actual construction an additional height, which will vary according to the nature of the material, is always allowed for the subsequent settlement or subsidence of the mass. As soon as the rough embankment is completed to full height, and has been allowed sufficient time for settlement under the influence of weather and of its own weight, the side slopes are neatly trimmed off, or made up to correct section. It is usual to leave the upper surface somewhat above the true 'formation' level, to allow for any further subsidence that may take place under the weight and vibration of the traffic. Wherever possible, the completed slopes of both cuttings and embankments are covered with good soil and are sown with grass seed, or turfed.

When deep valleys, rivers, large streams, or minor water-courses intersect the alignment of an embankment, the construction of great viaducts, bridges, or culverts becomes necessary, either to avoid the building up of enormous earthworks, or to provide a free passage for the water. Where embankments are high the smaller culverts are usually arched over at a low level, the line of earthworks being continued above them. In other cases the bridges or culverts are carried up nearly to formation level, and the openings are then either arched over, or are spanned by beams or 'girders' of wrought iron or steel, which carry the rails. In this case a break occurs in the continuity of the embankment, and the adjoining ends of the earthwork are protected and supported by masonry wing walls, projecting from the abutments of the bridge or culvert. Ample time for the setting of the mortar or cement used in these masonry structures is always allowed before the full weight of the earthwork is placed upon or against them.

The carrying of a line of railway over deep gorges or valleys,

large rivers, or it may be arms of the sea, is usually effected, either by continuous and often lofty viaducts of masonry, or by means of a succession of iron or steel girders, sometimes of great stretch from one support to another. The girders of bridges are supported on masonry or iron abutments, and a line of intermediate piers, so disposed as to cover the entire waterway of the river. The size of the individual openings is not a matter of arbitrary selection, but will in each case be decided by the engineer on grounds of economy or necessity. The most economical size of span will primarily depend on the cost of the piers including their foundations, and the greater the estimated cost of constructing these, the larger in ordinary cases will be the size of the girder spans which it will be economical to adopt.

Tunnels, viaducts, and bridges of enormous magnitude have in recent years been carried out in various parts of the world in connection with railways. Excluding a few examples of exceptional dimensions, some of the most important of these are to be found on Indian railways, and will be specially referred to in some detail in subsequent chapters. In the meantime it will be of interest to note the magnitude of a few of the most prominent examples, both of tunnels and railway bridges, which have been constructed by the science and skill of railway engineers.

The tunnel carried through the main part of the Alpine range at St. Gothard is 9¼ miles long. It is situated 4000 feet above the level of the sea, a level reached only by a series of massive and stupendous works, and is situated from a mile to two miles below the surface of the mountain.

The Mount Cenis Alpine tunnel is nearly 7½ miles long, and is more than a mile in depth, within the bowels of the earth. The tunnel carried beneath the Severn, between Bristol and South Wales, is 4½ miles long, including approaches. The river or arm of the sea lying above the tunnel is more than 2¼ miles wide. Owing to special difficulties from influx of water, seven years were occupied in driving the heading of this tunnel. It is made for a double line, and is lined throughout with brickwork in cement, from 60 to 70 millions of bricks having been used for the purpose.

The tunnel at Stand Edge, on the London and North-Western Railway is 15,705 feet, or nearly 3 miles long. The Khojack tunnel, on the north-west frontier of India, is nearly $2\frac{1}{2}$ miles long. The tunnel at Bramhope, near Leeds, is 11,010 feet, or rather over 2 miles long. The above examples comprise the most important railway tunnels in the world.

The largest existing railway bridge is that over the Firth of Forth. This extraordinary structure has two enormous openings, each of 1700 feet; two of 675 feet; fourteen of 168 feet, and six of 50 feet, and has a clear headway for navigation above high-water of 150 feet. The total length of the bridge is over $1\frac{1}{2}$ miles. The Lansdowne Bridge over the Indus at Sukkur has one magnificent span of 820 feet, and three of smaller dimensions. In America the Great International Railway suspension bridge, spans the Niagara River by a single opening of 800 feet from tower to tower, and the rails are 250 feet above the surface of the river. The Cincinnati Bridge has a clear opening of 515 feet.

The central pier of the Britannia tubular bridge over the Menai Straits is 230 feet high, the shore abutments being each over 160 feet. It has four large openings, those in the centre being of 460 feet clear span.

The new viaduct over the Firth of Tay is probably the longest railway viaduct in the world over continuous water. It is no less than 2 miles in length, consisting of 86 openings of various kinds, from 50 to 245 feet, of which thirteen are large spans of 245 and 227 feet each, carried at a height of $141\frac{1}{2}$ feet above the lowest foundation, and 77 feet above high-water in the Firth. The Saltash Bridge over the Tamar, near Plymouth, consists of nineteen spans, seventeen of which are small, but the remaining two, span the main river in two openings of 455 feet each. The height from the foundation to summit being 260 feet. The Hawkesbury Bridge in New South Wales has seven spans, each of 416 feet.

Such are the formidable dimensions attained by a few of the principal structures that have been required to reduce the natural inequalities of the earth's surface, and create that uniform 'formation'-level requisite for the purposes of a line of railway.

Along its course, especially in thickly-populated districts, it becomes necessary to provide for frequent cross-communication from one side to the other of that enclosed strip of land occupied by a railway. Public and private roads of all kinds will be carried across the line by means of service-bridges, passing either over it or under it, and these works are often very numerous and costly. In very flat country, where the level of the rails and the surface of the roads will commonly be more or less coincident, the construction of such bridges involves an extensive series of embankments, or cuttings, either for the road or the railway, in order that one may be made to pass over or under the other. In such cases, unless the road be of an important character, 'level-crossings' are resorted to. Gates are provided, which close alternatively across the road, or across the railway, as required, and an attendant or gate-keeper is maintained in constant charge of these gates; a small house being built alongside for his accommodation. The ordinary position of the gates is across the line of railway, leaving the ordinary road free for public traffic, but when any train is due their position is reversed until the train has passed. Sometimes the gates of a level-crossing are mechanically connected with signals which, actuated by the movement of the gates themselves, either remain at danger or allow the train to proceed, according as the gates are either closed or open for the passage of the train. In some cases, especially in the neighbourhood of stations, the movements of the gates are controlled by a lever worked from a 'signal-box,' and are mechanically connected, or as it is called, 'locked,' with the ordinary station, or special signals.

Both sides of a line of railway, unless very exceptionally circumstanced, are commonly provided with some form of fencing, in order to prevent accidents from the straying of cattle on the line of rails, and to reduce the danger and opportunities of trespass offered to the general public. Fences are of all kinds, such as an ordinary ditch and bank, the latter sometimes planted. Posts and rails of wood, thick live hedges; fences of iron wire, and stone-walls laid dry or otherwise. In India, but more especially in America, railway lines are, however, sometimes more or less completely unfenced, and in the latter

country not only in thinly-populated districts, but also in the neighbourhood of towns and villages. The people are warned to keep out of the way of the trains by the continuous clanging of the engine-bell, and stray cattle are promptly removed from the track by the peremptory action of the 'cow-catcher,' placed at the head of the engine.

CHAPTER IV

CONSTRUCTION OF LINE—'PERMANENT WAY'

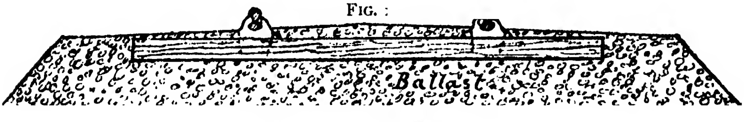
Permanent way—Ballast—Gauge of railways—English 'standard' gauge—Examples of gauges of different countries—Wheel flanges—'Clearance' and coning of wheels—Design of permanent way—Rigidity and elasticity—Early use of stone blocks—Sleepers and their object—Kinds of sleepers—Cross and longitudinal—Preservation of wood sleepers—Metal sleepers—Sectional forms of rails—Double-headed and flat-footed—Bull-headed irreversible rail—Increase of weight of rails—Railway chairs and keys—Spikes and trenails—Design of railway chairs—Tread of vehicle wheels—Inclination of rails—Flat-footed rails and fastenings—Length of rails—Fish-joints—Contraction and expansion—Check rails—Sidings—Cross-over roads—Switches and crossings—Facing and trailing points—Locking of switches.

Permanent way. As soon as the whole, or any sufficient length of a new line of railway has been completed to 'formation' level, and the earthworks have been allowed sufficient time to settle and become firm, the laying of the 'permanent way'—or the actual road on which the trains run—commences. This road, or line of way, consists of continuous pairs of end-connected rails, secured at a certain distance apart from each other by suitable fastenings to some form of 'sleepers' placed at close intervals, and imbedded in a mass of 'ballast' laid on the formation surface of the railway. 'Ballast,' which is usually considered part of the permanent way, and is, in fact, its foundation, is composed of a variety of hard unfriable materials, such as broken stone, clean gravel, sea shingle or pebbles, and slag from blast furnaces. Hard-burnt brick and sand are also in cases of necessity sometimes used for ballast, but are inferior. The main desiderata of good ballast are, that it should be entirely free from all substances which are soluble and liable to disintegrate under the action of water, that the particles of which it is composed should be of such size and hardness as not to crush or break up under the weight and impact of heavy blows, and that at

the same time they should not be light enough to be moved or lifted by the vibration or wind created by passing trains.

The height from formation level to the top of the rails on embankments is usually two feet. In cuttings it is sometimes more, in order to allow a greater depth of ballast below the sleepers for efficient drainage. The thickness of the ballast below the bottom of the sleepers is commonly one foot, and it is especially important that this portion of it should be of the *hardest* material. It is also considered better that it should be broken or screened to a larger general size than that used for the upper portion, so that it may allow rain-water to rapidly drain away from it. A medium and uniform size both for the upper and lower ballast is, however, often employed. The upper ballast reaches the level of the under side of the rails, and it is usually thickened towards the centre between them, so as to lightly cover the top surface of the sleepers, which if of wood are thereby protected from fire, which is sometimes dropped from the engine furnaces. In cases where the rails are supported on chairs, and are fixed by keys—especially of wood—the top ballast is also packed round the latter, and serves to protect them from shrinking and loosening under the heat of the sun. The width of the ballast on the upper surface generally extends about 18 inches beyond the ends of the

FIG. :



PERMANENT WAY ON EMBANKMENT.

FIG. 2.

PERMANENT WAY IN CUTTING.

sleepers—which may vary in length according to gauge—on each side, and the sides terminate in slopes of 1 to 1. In cuttings, to save width, the sides of the ballast are often retained within two vertical walls of dry packed stone. Figs. 1 and 2 represent sections of railway permanent way of English standard gauge, and will be useful to refer to.

The 'gauge' of a railway is the exact distance apart at which the inside edges of the top platform of rails are set by an iron instrument, commonly employed for the purpose, called a 'gauge,' and a variety of such gauges have been adopted in various parts of the world. Some uniform width between the rails, however, is almost universally adhered to over large systems of connected lines, so as to avoid the many inconveniences resulting from a break in continuity. The standard gauge of railways in England is 4 feet 8½ inches, but a few lines of narrower gauge occur in the hilly districts of Wales, or have been employed in other places under special local conditions. A large portion of one important railway system, viz., the 'Great Western,' was originally constructed at the broad gauge of 7 feet, but this has now been changed to the standard width. The English standard gauge of 4 feet 8½ inches is used to a greater or less extent almost all over the world. The most important exceptions are India and Ceylon, where the principal gauges employed are 5 feet 6 inches and 1 metre (or 3 feet 3⅜ inches). Spain, Portugal, Brazil, and Chili also employ almost entirely the 5 feet 6 inch gauge. Ireland, New Zealand, Victoria, and South Australia have decided in favour of 5 feet 3 inches; and Russia is practically the exclusive possessor of a 5-foot gauge. The United States of America have indulged in a great variety, from 8 feet down to 3 feet—the English standard gauge being included amongst them; Japan, Tasmania, Cape Colonies, Queensland, and to a great extent Norway, have remained constant to a 3 feet 6 inches gauge.

Each pair of vehicle wheels are provided with projecting flanges running inside the rails, so as to keep the vehicles from leaving the track; but the distance apart of these flanges is not made so as to exactly or tightly fit the gauge, but is usually about one inch less, allowing what is called a 'clearance.' On curves also the gauge itself is, in practice, made somewhat full, so as to permit a still greater lateral play or side movement of the wheels. The wheels of railway vehicles are rigidly attached to their axles, which revolve with them, and moreover all the axles of one vehicle are usually fixed rigidly parallel to each other. The outer rail of a curve is obviously longer than the

inner rail, hence, to avoid an excessive dragging and grinding action of the wheels against the rails, it is desirable that some provision should be made to enable the outer wheels on curves to travel over the greater distance in the same time as the inner wheels take to travel over the lesser distance. It is attempted to effect this by slightly coning the treads of the wheels from the flanges towards the outer edges. To a certain extent, in consequence of this coning and the tendency of the vehicles to proceed in a straight line and press against the outer rail, the exterior wheels on curved portions of the road do run on a slightly larger diameter than do the inner wheels, and thus advance a greater distance at each revolution of the axle; but the object in view is very imperfectly realised in practice, and the inner edges of the rails on curves are always subject to much abrasion. Nevertheless, a pair of wheels, one of which is in any degree larger than the other, if rigidly joined by an axle, will tend to roll in a circular path, hence the coning of the wheels is of some value in reducing resistance on curves, and in neutralising the tendency of the vehicles to leave the track.

In designing the permanent way of a line of railway, it is necessary to ascertain what are the severest ordinary and extraordinary strains, both vertical and lateral, to which each of the component parts of the line of way may be subjected, and to impart to each of these a strength and solidity more than sufficient to withstand such strains. At the same time, a certain degree of flexibility and elasticity must be permitted to the whole permanent way, so that it may yield a little to the stresses, in order to secure freedom from jar and hardness, and allow the vehicles to run with ease and pleasantness of motion.

It will not be necessary to detain the reader with any minute account of the various component parts of the permanent way, which, in addition to the ballast already spoken of, consist of the sleepers, the rails, with attachments and fastenings, and the points and crossings. In the early days of railways it was supposed that the permanent way could not be made too rigid, and in order to secure this rigidity heavy blocks of stone were employed in place of the elastic

wood or iron sleepers now universally used. These blocks were about two feet square and one foot thick; on each of them a cast-iron chair or seat for the rail, was attached by wooden trenails, driven into holes previously prepared in the stones. They were placed under each rail at a distance apart of about three feet. On the original London and Birmingham Railway upwards of 150,000 tons weight of stone blocks were laid down, all of which had to be removed, owing to the hardness and want of elasticity in the road, and the consequent severe wear and tear imposed on the vehicles. The object of a sleeper is to support the rails and distribute the load carried over a considerable surface of the ballast. Except in countries where wood is either very expensive or is especially liable to rapid decay, or other injury, wooden sleepers are now almost universally employed. For the standard English gauge they are made 9 feet long and rectangular in section, viz., 10 inches wide and 5 inches thick, although half round, and other sections are occasionally used. In Europe, sleepers are commonly made from Dantzic or Memel fir, pitch pine, and occasionally oak. In India, for the 5 foot 6 inch gauge, the sleepers are 10 feet long and 12 inches by 6 inches in section, and teak, oak, sal, and other hard woods are more generally employed, as well as a large proportion of metal sleepers, either of cast-iron, wrought-iron, or steel. In the case of metal sleepers, the chairs or seats on which the rails rest nearly always form a part of the main body of sleeper.

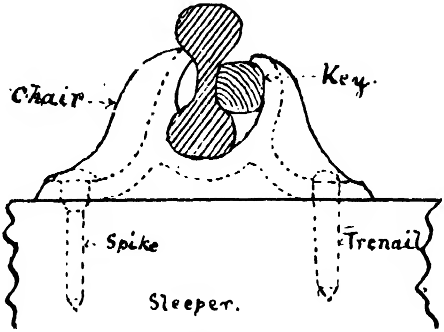
Sleepers are of two principal varieties, viz., either 'cross,' that is, placed at a certain distance apart, at right angles to the rails, in which case they also serve to keep the rails in gauge; or 'longitudinal'—that is, placed in a continuous line under the rails, when, in order to preserve the gauge, transoms and bolts, connecting at intervals each line of sleeper, are necessary. Longitudinal sleepers require to be of larger section than cross sleepers, and necessitate the use, economically speaking, of the flat-footed form of rail. Owing to the rail-foot lying parallel with the fibre of the wood, continuous packing pieces of wood, with the fibre at right angles to the rail and sleeper, are required. Longitudinal sleepers are also only economical on lines of very wide gauge. Rails laid on

them make a very easy and smooth road; but the arrangement is attended with some inconveniences in maintenance, besides having other disadvantages, and notwithstanding that a lighter rail can be used to do the same work, is—for the narrower gauges—expensive; hence longitudinal sleepers have practically been almost abandoned. 'Cross' sleepers are placed at right angles to the axis of the road, at a distance apart varying according to the weight and strength of the rails. A common distance is about 3 feet from centre to centre, and 2 feet at the places where rail-joints occur. If placed much closer than this it becomes difficult to properly pack the ballast under them. In order to preserve sleepers made from the softer kinds of wood from premature decay, they are often subjected to chemical treatment, the preservative composition employed being forced into the pores of the wood by enormous pressure. Cast-iron bowl or, as they are called, 'pot' sleepers, consist of a pair of round or oval bowls, or 'pots' of cast-iron, connected together by a bar of wrought-iron passing through them, and secured at a proper distance apart by keys. Jaws forming a seat or 'chair' for the rail are cast on the top of the rounded bowls, into which the rails are fixed by wood or metal taper wedges. Most forms of metal sleepers are much the same in general features, although varying in detail to suit the nature of the metal employed.

The sectional forms of rails and the details of fastenings of permanent way, have exercised the ingenuity of more inventors, and have been the cause of more controversy among practical engineers than any other subject that could be named. So great are the multitudinous varieties which have been introduced, that it would not now appear possible to devise any untried arrangement. The eliminative selection of experience has however resulted in the 'survival of the fittest,' and, practically speaking, rails as now used are confined to two general types, viz., the I or double-headed rail, and the solid flat-footed rail. As regards material, the cast-iron rails used on the early tramroads were soon exchanged for those of wrought-iron, which in their turn have since given place to the more durable steel.

The I, or double-head section of rail was originally made—

and is still often used—with two equal bulbs, above and below, the intention being when one head was worn out by the traffic to reverse the rail and utilise the other head. This form of rail however, having no foot, requires both vertical and horizontal support. To supply this support, seats, or as they are



CHAIRED RAIL.

appropriately called, 'chairs,' to hold the rail were introduced, but it was found that the under-side of the rails were apt to be worn into hollows or indentures at the points where they rested on the chairs, and were thus rendered more or less unsuitable for reversing. The chairs were in consequence gradually increased in size and area so as to afford a larger bearing surface to the rail; but owing to this increase of weight it soon became cheaper to give up the idea of reversing the rails altogether. The surplus material in the lower bulb of the rail was therefore reduced, and transferred to the upper or wearing bulb, which was thus greatly enlarged, resulting in the economical, and now common form of the 'bull' or bulb-headed irreversible rail.

The continuous increase in the power and weight of locomotives has gradually led to a corresponding increase in the size and weight of rails necessary to withstand the increased loads, and wear and tear to which they are subjected. On the original Liverpool and Manchester Railway the rails weighed only 35 lbs. per yard of length, but the increasing weight of the engines soon obliged the directors to renew the road with rails weighing 60 lbs. per yard, and at the present day steel rails weighing 75 and up to 100 lbs. per yard are frequently used.

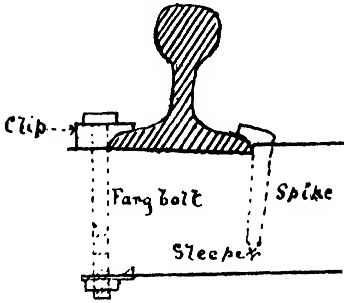
'Chairs' for supporting the I or double-headed form of rails are usually made of cast-iron, and have gradually increased in weight from 20 lbs. to 50 lbs. each. The jaws and seat of a chair are made of a form to fit the outlines of the rail, with a space left on one side—generally the *inside*—for the insertion of a taper wedge of wood or metal called a 'key,' which, driven firmly in between the rail and the jaw of the chair, prevents all lateral or vertical movement under the action of the traffic. The chairs are provided with two or four holes, through which iron spikes and hard-wood trenails are driven to secure them to the upper surface of the sleepers.

In every mile of single line, allowing 9 sleepers to every rail of 30 feet in length, there will be 3168 chairs, and the difference of *one ounce* in the weight of a single chair will mean about *one ton* in every 11 miles of road, or nearly 18 tons in every 100 miles of double track. It is, therefore, of some consequence that a railway chair should not contain in any detail of its structure, even a single ounce of metal more than sufficient for its exact necessary strength. Successive designers of railway chairs have therefore keenly and narrowly scrutinised every feature of their outline, and wherever a particle of metal more than sufficient for the exact necessary strength could be spared, it has been ruthlessly shorn off and suppressed. They had nothing in their minds but rigid economy and the strictest utility, but the altogether unintended result has been the production of a very graceful and pleasing outline, especially in the case of single chairs for the lighter forms of rail, where the principle of strict serviceableness and economy of material has been permitted to assume its fullest expression: so true it is that pure art outlines are ever the result of the severest simplicity and the absence of all redundancy. There are probably few objects that serve better to illustrate this important truth than the common railway chair of our permanent way.

We have already mentioned that the flat portion or 'tread' of the wheels of railway vehicles are not horizontal cylinders, but are slightly coned outwards. In order that such wheel-treads may bear evenly on the upper surface of the rails it is obvious that the latter ought not to be horizontal either, but should be slightly inclined inwards. It is found convenient to

effect this by tilting the whole rail, which is readily done by inclining that portion of the chair-seats on which the rails rest, and in this manner the upper surface of the rail-head is made to lie true to the inclination of the coned wheels.

The flat-footed form of rail is made with the usual rounded top bulb, but with a broad base or foot, 5 inches or $5\frac{1}{2}$ inches

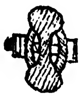


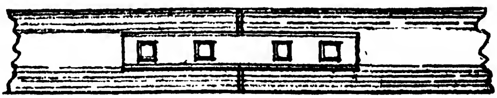
FLAT-FOOTED RAIL.

wide. It is, of course, not intended to be reversible, and as these rails do not require lateral support, chairs are not strictly required. The London, Chatham, and Dover Railway adopted a flat-footed form of rail, supported on low cast-iron chairs, the object in this case being to distribute the weight over a larger area of the sleepers. The arrangement in the case of this line has been since superseded by the employment of the double-headed rail and ordinary chairs. Generally speaking, however, flat-footed rails are seated directly on the sleepers, and to give them the necessary inward inclination the upper surfaces of the cross-sleepers are adzed to the extent required. This form of rail has great lateral stiffness, enabling it to resist the outward thrust of the wheels, and has, moreover, no deficiency of vertical strength. The bearing area on a cross-sleeper 10 inches wide will be as much as 50 to 60 square inches, and the rail-foot lies across it at right angles to the fibre of the wood. Although this bearing area is less than that of the larger chairs now used —principally to prevent the under side of double-headed rails from being damaged—it is found sufficient in ordinary cases to prevent any crushing of the harder woods, whilst in the case of the softer kinds of sleepers, 'bearing plates' of wrought-iron are often introduced between the foot of the rail and the sleeper.

The chief defect of the flat-footed form of rail—used, as it generally is, without chairs—as compared with the double-headed chaired rail, is found in the relative insecurity of the fastenings. Where first employed these rails were spiked or bolted to the sleepers through holes bored through the foot of the rail, but this was found inconvenient, not only as too rigidly determining the distance apart of the sleepers (the holes being bored at the time of manufacture of the rails), but the rails themselves were unduly weakened. To avoid the necessity of passing the spikes or bolts through the foot of the rail, the bolts are now provided with iron 'clips' projecting over the rail foot. Where the traffic is not heavy, spikes with projecting heads are alone used, but in other cases 'fang bolts' (see Fig.), passing completely through the sleeper, with a claw or fang on the under side and a clip above, are employed, either at every sleeper, or at the extremity of each pair of rails only, the intermediate points being secured by spikes. The severe side-pressures exerted against the rails by the blows of the wheel flanges under the swaying motion of rapidly running trains, have a tendency to thrust the rails over outwards, and either to partially draw out the spikes, or to put a severe strain on the fang bolts and clips. Nevertheless, the flat-footed pattern of permanent way possesses many economical advantages, and is very largely used.

Rails, of whatever pattern, are made in lengths of 20 to upwards of 30 feet, and it is plain that where the ends of two rails come together it is necessary to firmly join them. When a sailor wishes to mend a broken spar he often lays a piece of timber on one or on both sides of the fracture, and lashes the whole round with rope. This in nautical phraseology is called 'to fish' the joint. The joints of rails are also 'fished.' Two





pieces of iron called 'fish plates' are made to fit the sides of the rails, and are bolted across the joints by bolts passing through holes in the web of the rail. Four bolts, *i.e.* two on each side of the joint, are usually employed, and the section of iron given

to the fish-plates is such that when they are securely bolted up to the sides of the rail the combined strength of the plates, and also that of the joint itself, is at least equal to that of the solid rail. Rails, like all other objects, contract and expand under the influence of changes of temperature, and in order to prevent distortion of the road resulting from these movements it is necessary to allow a little space between the abutting ends of each pair of rails. The fish-bolts passing tightly through the web of the rails would, however, prevent their elongation or contraction were it not that the bolt-holes are made slightly oval in a longitudinal direction, and the necessary movements are thus duly provided for. In practice it is necessary, moreover, that the fish-bolts should not be screwed up too tightly, otherwise the friction between the fish-plates and the sides of the rails would be so great as to prevent the movements taking place, and the road would in consequence be forced out of shape, and distorted into a wavy line, instead of preserving that perfectly straight and even alignment which is so essential in the permanent way, and the absence of which is always so uncomfortably felt by the railway traveller.

On very sharp curves it is sometimes necessary to lay down close to the inner rail what is called a 'check-rail.' This check-rail allows only an easy play to the wheel flanges, and its object is to check the tendency of the outer wheel to mount the rail on curves. Double check-rails are also sometimes used over long lofty bridges, even where the road is straight, or in other situations where any derailment would be exceptionally disastrous. The check-rail when used with the flat-footed form of permanent road is often only a stout angle iron, bolted firmly down to the sleepers, and as an additional precaution it sometimes projects to a slightly higher level than the top of the running rail.

On every line of railway, besides the main line or lines forming the traffic road, numerous side lines of way are required at fixed places or stations, so that trains or detached engines and vehicles may be passed on and off the main tracks. These various 'sidings,' as they are called, are connected with the main lines, and with each other, by diagonal connecting, or 'cross-over' roads, laid with long easy reverse curves. At

either end of the cross-over roads the junction is effected by means of a pair of pivoted movable rails called 'points' or 'switches,' so constructed that, placed in one position, the flanged wheels of the moving vehicles will continue to move along the principal track; but placed in a reverse position, the wheels will be constrained to enter the cross-over or diverging road. At the places where one rail has to pass across another, a gap in the rail to be passed over is introduced by laying down a grooved table of steel, called a 'crossing,' which admits the passage of the wheel flanges along the grooves, and allows the tread of the wheels to roll smoothly along the upper surface without interruption.

Points or switches are of two kinds, respectively called 'facing-points' and 'trailing-points,' but these terms do not denote any difference in mechanical construction, but refer merely to their position with reference to a moving train. When an engine approaches, and first comes in contact with switches at their free movable end, the points are called 'facing,' but when the heel or pivot end of a pair of movable rails is first touched by an engine—moving in this case in a contrary direction—the points are called 'trailing.' Facing-points cause the vehicles to diverge from a main track or siding into a branch or cross-over road. Trailing-points cause the vehicles to converge into a main track or sidings. Points and crossings may thus be regarded as gates of entrance and exit, admitting the passage of trains or vehicles from one line of way to another, and as such, are always more or less dangerous portals, unless the traffic through them is maintained under perfect control.

Switches are usually kept locked so as to restrict the traffic to one road only, and are only unlocked for the time necessary to admit the passage of vehicles into or out of that road, as may be required. The working as well as the locking and unlocking of points is sometimes in country districts where the traffic is small, directly effected at the switches themselves by a pointsman in charge, but where the traffic is at all heavy the manipulation of all the switches in a station yard is concentrated and carried on from one signal station or box, from whence all the signals are also worked. The various adjustments of the

switches, and the movement of the signals are, moreover, effected in unison by means of a special mechanism. This interlocking of switches and signals will be further alluded to in the next chapter, when we are dealing with the signalling arrangements on a line of railway

CHAPTER V

CONSTRUCTION OF LINE—'STATION BUILDINGS AND MACHINERY'

Station buildings and machinery—Provision for growth and expansion—Passenger roadside stations—Height of platforms—Goods accommodation—Large terminal passenger stations—Principal varieties and relative advantages—Buffer stops—Large terminal goods stations—Varieties of plan—London goods stations—Locomotive depôt—Running sheds, pits, and watering—Turn-tables, triangles, carriage turntables, and traversers—Water cranes, tanks, and ashpits—Pick-up watering—Central workshops—Outdoor apparatus for signalling—Early history of railway signalling—Colours—Time signals superseded by space signals—Block system—Forms of outdoor signals—Colour blindness—Fog signals—Situation and details of signals—Correspondence of signals with points or switches—Interlocking of signals and outline of apparatus—Value of the system—Platform and other signals.

Station buildings and machinery.

RAILWAY stations, whether passenger or goods, are of largely varying size and importance, from the smallest roadside pick-up station, at which only a few trains may stop, to the often gigantic terminal stations required in a capital city, into and out of which flows, night and day, a continuous and never-ceasing stream of busy traffic. Accommodation and conveniences for the receipt and despatch of goods—according to the commercial importance of the locality—will either be combined with, or be altogether distinct from the passenger arrangements.

The growth and development of traffic on almost every line of new railway is commonly so steady—even if not always immediately great and rapid—that a judicious engineer will, from the very commencement, in designing all station accommodation, make ample provision in his plans for a large and economical possibility of extension. He will, however, *actually* provide in the first instance for the minimum requirements only, and this provision will be based upon the best judgment he can form as to the smallest immediate necessities of the case. It is on

the engineer's forethought and wisdom in this matter of initial economy, combined with initial arrangements for growth and expansion, that much of the future economical working of the railway will depend.

In the case of every passenger station, even one intended for the accommodation of a village or very small town, the length of the platform will be made at least equal to that of the longest trains which are required to stop at it. This length will depend on the gauge and importance of the railway, but will in ordinary cases reach 600 to 800 feet on main lines. Unless land is exceptionally expensive, or the station has to be built on a high embankment, or in a deep cutting, or other difficult situation, the *width* of the platform will be liberal and spacious, 25 to 30 feet being now frequently allowed. The height of platforms for passenger traffic has been, in practice, subject to great variations, chiefly on grounds of economy of materials. Probably, however, the most convenient height, both for the work of the station staff in crossing the lines and in handling luggage, as well as for the ease and comfort of passengers, is about 6 or 8 inches below the floor-level of the carriages.

The booking-office is most conveniently placed on that side of the line nearest to the town or village; but if there are up and down lines a second platform and a waiting shed will be provided on the opposite side. It is important that booking-offices and waiting-rooms should, whenever possible, be on the same level with the platforms and the outside approaches to the station, and this requirement is always kept in mind, both in the original grading of the line and in the selection of the precise spot for the station. Where the arrangement is impossible, easy inclined planes will be better than steps or stairs between the approaches and the platform. The minimum amount of accommodation provided in station offices, whether for the public or for the staff, will indefinitely vary according to the circumstances of the traffic in each particular case, but the smallest station will always include, in addition to the platform, a public booking or ticket-office, a clerk or station-master's office adjoining, a general waiting-room, store-room, urinal, and some portion of covered platform or outside shelter, either on one or on both sides of the line. The ordinary home

and distant signals, a clock, supply of water, and arrangements for lighting will be among the necessary provisions.

If the roadside station is important enough to require separate goods accommodation, goods sidings and a separate platform will be provided somewhere near the main offices, so as to be under the convenient inspection of the station-master at all times. The goods platform will be made of such a height as to be level with the floor of the wagons brought up alongside of it. Shed room will also be constructed in proportion to the requirements of the case, arranged so that perishable goods may be loaded or unloaded under cover, and that carts or vans may be able to approach the loading platform. It is usual to make the doors of goods sheds sliding instead of hinged to economise space and promote convenience. The principal fittings necessary for the goods side of a roadside station will be a small crane for lifting heavy weights, a weighing machine, and perhaps a weigh bridge, a loading gauge, a lock-up store, and small office with clock for the booking-clerk, together with a supply of water and lighting arrangements. Intermediate stations for large and important towns or junctions, whether for passengers, for goods, or both combined, will of course be greatly enlarged to suit the amount of traffic expected to be dealt with.

The arrangement and disposition of a large terminal passenger station—usually situated within the limits of a great city—depend not only on the traffic, but is often greatly determined by the cost and shape of the site that may be available. There are, however, three principal varieties of terminal stations, important examples of which are to be found, and against, or in favour of each of which, certain advantages, and other corresponding disadvantages may be urged. The three varieties are distinguished by the relative position of the main station offices, with reference to the departure and arrival platforms. These offices may be situated, either along one *side* of the station; they may be placed in a *central* position, or they may be situated at the *end* or extremity of the terminus. When the main station offices—comprising booking, luggage, telegraph, station-master's, and parcels offices, cloak-room, waiting-rooms, refreshment-rooms, lavatories, etc.—are placed

along the *side* of a terminal station, a long main departure platform is very conveniently situated immediately opposite to them, and passengers reach this platform near its middle. The arrangement is also convenient where large quantities of luggage have to be dealt with, as the luggage office and weighing apparatus is located close to the departing trains. On the other hand, access to a second, or to other departure platforms is difficult, and is only to be effected, either by an inconvenient and distant end-passage, by an over-bridge, an under-passage, or by a movable crossing platform, which can be put into position, or removed as required; so that where a large number of trains are required to be despatched from several departure platforms, the inconvenience of this want of easy access to all except the first, is a disadvantage. The plan of placing the general booking and station offices in a *central* position is commodious in many respects, but is less usual. The arrangement admits of two long departure platforms, one on each side of the buildings, to which easy access is gained near the middle portion of the trains. It is said, however, that this arrangement disperses the staff, and requires a large number of station hands to carry on the work. However this may be, there is little question that where a very heavy and frequent passenger service has to be dealt with, the third arrangement, or that where the main station offices are situated at the *end* or extremity of the terminus, is on the whole preferable to the other two.

The principal advantages of this last arrangement are, that there are no difficulties in the way of using any of the platforms, as occasion may require, either for departure or arrival of trains; a very important desideratum. A discharged train which has just arrived, can thus be used as a fresh departure train from the same platform, and generally much shunting and moving of trains and vehicles will be avoided. The arrangement is also very economical in space; a highly important matter where land is valuable, as each platform will have a line on either side of it, requiring to be but very little wider for the use of two trains than for one only. In this form of terminus a wide space is provided between the end of the lines of rail, and the station offices, to which the public

may be freely admitted without interference with the service of the trains. Travellers and their friends can be prevented by barriers from entering on the train-platforms, except by ticket, and can be admitted only a short time before the train departures, an arrangement which is hardly possible in the case of the other two plans. From a railed-off portion of this end platform, luggage also can be weighed, carried to the trains, and loaded into the train luggage-vans, with more freedom from press and intermixture with the passengers; the whole work of the station is more concentrated, and can be carried on with fewer hands; the porters passing from one platform to the other inside the barriers as trains depart or arrive. Perhaps the only disadvantage of this plan of terminal station is, that passengers approach the trains from their ends, instead of about their middle, and consequently have to walk, and luggage has to be taken a longer distance than when the general offices are situated either at the side, or in the central portion of the station premises.

In all three arrangements, roads for the approach and departure of cabs are provided—on one side—or it may be also between two of the principal arrival platforms. The entrance to the main cab road is, wherever possible, made at the end farthest away from the exit, so that empty vehicles may enter by a different road from the loaded ones leaving the station.

At the points where the several lines of way suddenly come to an end at all terminal stations, it is necessary to provide some means of arresting the motion of vehicles which may overrun the point at which they should have stopped. This is done by fixing at the end of each line of rails a strong massive buffer-stop of timber and iron, provided with spring buffers fixed at the same height, and similar in character to those on the vehicles.

The planning out and arrangement of a large terminal goods station, so as to combine the greatest facility in marshalling the incoming and outgoing trains, and working them into and out of the various platform sidings, whether for loading and despatch, or for receipt and unloading, together with the utmost convenience for the rapid entrance and exit, loading and unloading of the ordinary road vans or carts, for the

receipt and delivery of goods, is one that taxes the skill of the designer more than any other detail of railway accommodation, and perhaps in no particular does the practice of the great railway companies differ more than in the ground plan and general arrangement of their terminal goods stations. The ultimate object in every case, however, is to carry on with a maximum of convenience and rapidity the enormous operations frequently involved.

At some of the larger London goods stations, 1500 or 2000 men may be nightly employed in loading and unloading goods, over an area of 15 to 20 acres, containing perhaps 20 miles of sidings, and disposing in a few hours of perhaps 1000 or 1200 wagons, comprising 3000 to 4000 tons of merchandise, exclusive of minerals. The 'outwards' or despatch work is largely carried out in the early part of the night, in readiness for the 'inwards' or receipt traffic usually dealt with in the early hours of the morning, and so great is the perfection in the arrangements now commonly attained, and the order and rapidity with which the work is carried on, that often hardly more than an hour will elapse between the consignment of goods and their despatch by train to their various destinations.

At all terminal stations, and at varying intervals along a line of railway—intervals dependent on the conditions of the traffic—locomotive depôts will be established, to provide for the proper grooming and victualling of the ponderous iron horses. These depôts will be furnished with 'running' or shelter-sheds for housing the engines. Inside the sheds will be continuous pits between the gauge of the rails, to allow free passage beneath the locomotives for examination of the machinery, and a plentiful supply of pure water, supplied at considerable pressure from an elevated tank, for washing out the boilers and general cleansing purposes. The sheds will also usually contain some workshop accommodation for executing minor repairs. Near the running sheds, 'ashpits' between the rails for receiving discharged ashes from the engines, hollow water-cranes, by means of which the engines may be furnished with water, and stages for conveniently taking in supplies of fuel, will be provided.

Terminal stations will also invariably contain some provision

for turning, or reversing the running position of the engines. In most cases this is done by means of what is called a 'turntable;' but in country localities, where the expedient may be admissible or convenient, the engines can be turned on a short length of railroad laid down in the form of a triangle, of size sufficient to enable the engines to pass round it. Points and crossings are, of course, provided at the apex of the triangle and at its points of junction with the main road. A 'turntable' is a centrally pivoted revolving platform, of a diameter and strength sufficient to carry an engine with its tender, having a line of rails on it coincident and level with the adjoining line of way. The engine being run on to the platform and stopped, the whole by suitable mechanism is revolved a half turn, when the position of the engine will be reversed, and it can then be run off the platform on to the line of way by which it came. In crowded terminal or other station yards, turntables for carriages enabling them to be quarter turned, and pushed on cross lines from one line of rails to another, instead of passing by cross-over roads, are also sometimes employed; but it is generally more convenient in such places to use a 'carriage traverser,' or low dwarf frame running on cross lines, on which the carriage or vehicle is first mounted, to effect this purpose. When these are used, at least one carriage turntable will be provided, in order to reverse the running position of the carriage and waggon stock when desired.

At sundry intermediate stations along the line, water-tanks and cranes for refilling the engine-tanks with water, and 'ashpits' for receiving the discharged ashes from the engines, will also be necessary. The distance apart of these watering or ashpit stations will depend upon the varying conditions of the traffic as affecting the consumption of water, the capacity of the engine tanks; or the kind of fuel used. In cases where it is desirable that trains should run exceptionally long distances without the necessity of stopping to take in water, 'pick-up' water-troughs are employed on many railways. A long open trough of very considerable length, and kept filled with water, is constructed between the gauge of the rails, at convenient watering-places. Into this trough a 'dip-pipe' or scoop, attached to the bottom of the tender of the running train is

lowered, and at a speed of 50 miles an hour upwards of 1000 gallons of water can be easily scooped up and discharged into the tender during its passage over the trough.

Central workshops for the repair or reconstruction of the locomotive engines, and of the carriage and wagon stock of all kinds, are provided on all important railways. These may be located at one of the principal termini, but are generally placed in some central position with reference to the entire system of railways owned and worked by one company or agency.

Every railway station requires to be provided with an out-door apparatus for signalling, both by day and by night, so contrived that by it instructions may be conveyed from the stations to persons in charge of trains, in order to control the motions of the latter. It would be impossible within the compass of a few pages to discuss in an adequate manner the important matter of railway signalling. We will, however, endeavour to convey to the reader an outline and general idea of the main principles in accordance with which the movements of trains on a line of railway are controlled by the aid of that system of out-door signals, which has been necessitated by the rapid development of railway traffic, and which in many particulars has now reached so high a degree of perfection as to render the safe working of trains, so far as this matter is concerned, almost independent of human error or carelessness.

On the first lines of railway that were constructed, the need of fixed signals was unfelt. So few trains followed each other on the up and down lines nearly always provided, that nothing at first seemed to be required except a code of hand-signals, similar to that still used in station-yards for shunting or other purposes. This code of hand-signals, still almost universally employed, consists of the use of coloured flags, and the various attitudes of the arms of a signalman by day, and of coloured hand-lamps by night. A signal for 'all right' is given by holding out a white flag, or by stretching out the arm horizontally, or at night by showing a steady white light. A signal for 'caution' is given in daylight by a green flag, or by holding *one* arm straight up in the air, and at night by a green light. A danger or 'stop'-signal is given by showing a red flag, by holding up *both* arms vertically, or by waving a cap or some

other object violently. At night a red light is shown, or if no red light is available, by waving violently any other light across the line.

On the original Liverpool and Manchester Railway, when first opened, hand-signals only were employed, and it was not until about the year 1834 that on this line the first fixed signals were introduced for night use, by the simple expedient of fastening an ordinary lamp to the top of a post, showing a red light if it was desired that the train should stop, and a white light if on the contrary it might proceed. Even in the year 1841 the only fixed day-signal employed at stations on this railway was a flag run up and down a mast by means of a rope and pulley. The use of coloured objects, borrowed from the hand-signalling, was soon, however, extended to fixed signals. *White*, whether exhibited in the shape of a flag, a disc, an arm, or a light, came to represent safety or 'all right.' *Green* meant 'caution,' and *red* signified danger or 'stop.' These *colours*, whether by day or by night, for a long period were used simply as *time*-signals. Some description of fixed station-signal—scarcely any two railways using the same—such as a coloured disc, round or square, or a horizontal arm on a post (exchanged after dark for a coloured light), was displayed for both up and down lines. The red colour was shown directly a train had reached or passed a station, and remained exposed for five minutes after its departure, so as to stop any following train. The green signal, often carried on a shorter post, was then exhibited for another five minutes, so as to complete a ten minutes interval, after which either no signal at all, or the white 'all-right' signal was exposed. On some lines the *time*-intervals were varied to suit the special circumstances of the traffic, but before long, and soon after the introduction of the electric telegraph on railways, the main object aimed at in signalling completely changed. It was no longer sought to preserve an interval of *time* between trains, but to ensure an interval of *space*, and it is obvious at first glance that this was a vast improvement: for in case of a train breaking down, or from any cause not running to time between two stations, the time-signal would not prevent the following train from running into it.

Under the present system the colours of the old signals have been retained, but the use of the electric telegraph enables each line of way on a railway to be divided into certain *space-intervals* or 'sections,' and permits the establishment of a rigid rule or regulation, that no train shall be allowed by the ordinary out-door signals, to enter any section until the previous train has been signalled by telegraph to have left it at the other end. This, which is called the 'block' system, ensures, if the regulation is adhered to, that no train can ever overtake or run into another proceeding on the same line of rails.

The form of out-door signal apparatus now employed on all important railways, is that known as the 'semaphore,' which combines the use of colours by night with the relative position of a semaphore *arm* by day. This signal consists of a tall vertical post, which carries near its top a pivoted movable arm—or more than one if signals for several roads have to be given—the arm, projecting from the post in a horizontal position, indicates danger or 'stop.' Lowered to an angle of 45 degrees with the post, it indicates 'proceed cautiously;' or shut down entirely within the post, it signifies 'all right.'

In connection with the 'block' system, however, it is clear that only two signals are really required, viz., one to express the instruction, 'All right, you may go on, for the line is clear in front as far as the next signal-station;' and the other to express, 'Stop at once, for the section of line in front is *not* clear.' In the neighbourhood of towns it is an advantage to be able to discard the use of the white light at night, because it is liable to be confounded with other ordinary white lights, consequently in such situations the green-coloured signal has now almost entirely taken its place, and has practically come to mean 'all right' instead of caution. On the other hand, in the open country, the white light is superior to the green light, inasmuch as it can be clearly seen from a greater distance by the drivers of fast-running trains, and it is, therefore, generally retained under these circumstances. Similarly, the inclined or 'caution' position of the day-signal arm is now almost everywhere used to express 'all right,' the shut-down position within the post being discarded, this position having the objection of being rather the absence of any definite signal than an

affirmative one. The use of the three signals by night is, however, still adhered to on some lines, a purple light being substituted for the white light in the neighbourhood of towns.

As now used, therefore, in connection with the almost universal 'block' system, day-signals consist of a horizontal semaphore arm to indicate danger or 'stop,' and the same arm inclined at an angle of 45 degrees to indicate 'all right.' At night a lamp is lighted near the top of the signal-post, and a spectacle of red and green glass, or one of red only, is interposed in front of the light by the motion of the same rods that work the signal-arms, showing a red light when the arm is in the position indicating danger or 'stop,' and a green or a white light, according to situation, when the arm is in the 'all right' position.

These colours, now used in railway signalling, whether by the exhibition of coloured flags and other objects by day, or of lamps by night, were adopted at a time when that defect in human vision, known as 'colour-blindness,' was little known, or when its accompanying phenomena had been little investigated. Unhappily, moreover, the use of this colour-system of signalling has become so firmly bound up with railway practice all over the world, as to preclude the possibility of any radical change of principle being now thought of.

Modern scientific investigation into the facts of colour-blindness has clearly proved that a considerable and unexpected percentage of persons are unable from birth to interpret correctly one or other of the primary colours, especially 'red' and 'green:' that this defect in visual perception may be induced by excessive tobacco-smoking, either combined with or entirely without, the abuse of alcohol, and moreover that examples exist of persons whose eyesight is normal with respect to the colours of opaque, *non*-luminous objects, but who at the same time are colour-blind to luminous objects, especially of varying intensity (such, for instance, as railway signal lamps). In view of these facts, a duty, the importance of which it is hardly possible to exaggerate, is imposed on those persons responsible for the safe-working of railway trains, to ascertain by the most crucial tests that ophthalmic science may have rendered available, that the vision of engine-drivers and others is not only normal on first engage-

ment, but also by periodical examination to ascertain whether it continues in a healthy condition, seeing that these persons have under daily, and even hourly risk of human life and property, to read correctly the colours of railway signals.

The methods of test hitherto employed, whether by requiring the candidate to name the colours on prepared cards, read the actual outdoor signals, or by requiring him to match together the various colours of skeins of wool, irrespective of shade (known as the 'Holmgreens wool test'), when these tests are unaccompanied by the more stringent trial of correctly matching opaque against the colours of luminous objects of varying degrees of intensity—in a similar manner to the system of testing now adopted by the Admiralty in the case of candidates for the marine service—have been shown to be liable to extreme chances of error, even if they are not actually useless.

In England the subject has attracted great attention in recent years, and railway companies are beginning to be more keenly alive to its real importance. In Indian railway practice, however, really efficient methods of testing the eyesight of engine-drivers, signalmen, and others for colour-blindness are either largely unknown, or their application is singularly lax. It is sometimes urged that too great an importance is attached to the subject, inasmuch as very few cases of railway accident can in practice be attributed to colour-blindness, but in a large number of cases where accidents have arisen from some conflicting interpretation of signals, it has not hitherto been possible, without the aid of the more recently devised scientific methods of test, to prove that such misinterpretation was, or was not, due to this cause. To such of our readers who may desire to have a clearer idea of the theory and facts of colour-blindness, as bearing on railway signalling and the most improved methods of test now employed, a *résumé* of this important question will be found in Appendix J.

During the time of fogs or mist, when neither the arms nor the lights of fixed signals can be seen, *audible* signals are resorted to. At a certain distance beyond the fixed signals in the direction of an approaching train, special signalmen are employed to fasten on the rails by the aid of small leaden clips, percussion or 'fog' signals, which being run over by the engine

explode with a loud report. One such explosion means 'caution,' or proceed slowly, two or more in succession mean danger, or 'stop.'

Having now explained the form and kind of outdoor signals usually employed, it is necessary to indicate their ordinary situations. Every through station is provided with central or 'home' signals, as they are called, and two 'distant' signals, situated far away on either side of it. Terminal stations will of course require the latter on one side only. The main or 'home' signal-post is generally placed adjoining the platform, and either at or close to the main cabin or 'box' provided for the signalman. In consequence of the great speed at which trains travel, it is necessary that engine-drivers should know how the main signals stand some time before they can reach them. This is arranged for by the provisions of auxiliary or distant signal-posts on either side of the home signals, at a distance of a quarter to a half a mile away, the arms of which are worked by wires and rods connected with levers in the signal box. Each of these semaphore signal-posts will often be furnished with arms on both sides of it, or even tiers of arms one above the other, but in *every* case the arm or arms on one side of the post control trains running in one direction, and the arm or arms on the other side control trains running in the other direction. The driver of a train approaching any semaphore signals whatsoever, has only to consider the arm or arms on the *left*-hand side of the signal post; those on the right hand in no way concern him.

In all cases signal arms are counterweighted, so that in case the wires or rods connecting them with the working levers should at any time break, the arms will by their own weight fly to the position of 'danger,' and thus no further harm than some delay will ensue. The normal position of all signal arms is, moreover, horizontal, or at danger, and they are only lowered to the inclined or 'all right' position for the brief time necessary to allow a train to pass clear of it. At complicated junctions, or stations where there are a great number of lines, and consequently where there may be a great many signal arms one above the other on the posts, it is usual to arrange the order of their superposition, so as to correspond with a

numerical or other order in the various lines to which they refer. By the aid of these and numerous other suitable arrangements, which practically provide for all the possible complications that can arise, railway signals are made to convey permission to the driver of any train to proceed, or to command him to stop.

It will be obvious, however, to the most uninitiated person that much more than this is required. Whenever trains have to pass from one line of rails to another by those gates of entrance and exit called 'points' or switches, in doing which they may for a time obstruct communication on, or 'foul' one or several other lines of way, it is clear that the exhibition, and even the exact obeying of signals, will be no safeguard to the traffic, unless the working of these switches or 'points' is conducted in exact correspondence with the signals. If at any time these should be in contradiction the one to the other, conditions favourable to a collision or other accident will be immediately established. It is in order to prevent the possibility of this dangerous contingency that ingenious inventors have devised an interlocking mechanism for the levers of points and signals, so arranged that no signal arm can by any human effort be removed from its normal position of danger, unless all the points situated on the line of way controlled by that signal are previously placed in the proper position for the train to pass, and further, during the whole time that the signal arm is in the lowered position, permitting a train to proceed, by no human effort can the points be moved, nor can any other signal be shown, which will allow another train to proceed on any line of way obstructing or 'fouling' the first. The numerous levers which actuate all the points, as well as those which actuate all the signals, are concentrated and ranged side by side in the signal cabin, and are placed in mechanical connection with an interlocking mechanism, so devised that the *results* of the arrangement are very much the same as if a piano or organ was constructed in such a manner that no combination of notes could possibly be struck which were not in perfect harmony. So far as exact accordance between points and signals are concerned, a blind man might with safety be allowed to enter a signal cabin and pull over any of the levers of an interlocking

apparatus at random. He would probably produce delay in the traffic, but he could not produce discord between the points and the signals.

The main principle of the apparatus is, that so long as all the outside signals are at danger the point levers are free to move, thus permitting any shunting that may be necessary to go on under the protection of the danger signals, but if the signalman desires to lower any signal arm to the 'all right' position he cannot, by the conditions of the mechanism do so, until all the points concerned are *first* set in their proper positions of safety for the train to pass, nor whilst the signal arm is down can he move the points so set, or actuate any other signal concerned with any portion of the same line of way. The *man* and his liability to forgetfulness or error is in fact superseded by the unerring action of the machine. Trains may be derailed, engine-drivers may fail to see, or may disregard the signals, or brakes may refuse to act, but the perfect correspondence between the signals and the safety of the roads to which they refer is practically absolute.

The importance and value of interlocking apparatus will be illustrated when it is stated that at some London terminal stations, at the most crowded time of the day, eighteen or twenty trains may arrive, and eighteen or twenty trains depart within the hour, necessitating perhaps 120 operations of shifting points and signals, or an average of, say one in every 30 seconds, a work which it would be impossible for any unaided human being to carry on without mistake, even for a few minutes.

In addition to the ordinary outdoor signals, of which we have been speaking, platform arrival and departure signals are often used where trains are frequent. Numerous other signals are also employed for conveying instructions from one signal box to another, or between those concerned in the actual working of trains, and even between passengers and the train officials. Most of these are nowadays worked by electricity, and are of too technical a character to be here treated of.

CHAPTER VI

INTRODUCTION OF RAILWAYS INTO INDIA

Introduction of Railways into India—The India of early English occupation—Vivifying power of railways—Influence on the destinies of India—Outline of physical geography of the Continent—Principal divisions—Chief rivers of Hindustan—The table land of the Deccan—Western *ghâts*—Eastern *ghâts*—Principal rivers of the Deccan—Vindhyian mountains—Satpura and Aravalli ranges—Alluvial soil of Hindustan—Characteristics of Indian rivers—Coast line and paucity of sea ports—Madras, Bombay, Karachi, and Calcutta the focus of early railways—The first three main trunk lines—Early projects—The 'Great Eastern' Railway from Bombay—The 'Great India' or 'Great Indian Peninsula Railway'—Early history—First suggestion of the guarantee system—Early promotion of the 'East Indian Railway'—First despatch recognising desirableness of railways for India—Curious assumptions—Deputation of an experienced civil engineer from England—Committee appointed—Proposals for main clauses of contract and Government control—Report of Committee—Experimental line—Discussion of proposals—Views of the Governor-General—Prolonged negotiations—Preliminary agreements signed—Principal contract-terms under the guarantee system.

Introduction of Railways into India.

ALMOST exactly forty years ago—or, more precisely, on the 16th April 1853—the first length of railway in India, viz., the 20 miles between Bombay and Tannah, was opened for public traffic. Thus, only about twenty-two years later than the first introduction of railways into England, was planted on Indian soil the germ of that wonderful subsequent growth of trunk and branch lines of railway, the regenerating and awakening influence of which was there destined to produce more extended and far-reaching results than in any other portion of the globe, and to place in the course of a few years the India of pre-railroad days, and the India of the present, as far asunder as the poles.

Who cannot recall that familiar picture of India of the early British occupation, handed down through so many generations

of Englishmen? Its vast roadless plains, stupendous mountains, and almost impassable rivers. Its gorgeous wealth and abject poverty. Its subtle philosophy and depths of grossest superstition; the singularly unchanged and apparently immovable habits and customs of its dense swarm of dusky inhabitants; the living embodiment of an ancient civilisation extending backwards to the earliest dawn of history. A land where the very names of innovation, progress, energy, and the practical arts of life were unknown, or were abhorred, and which appeared sunk in a lethargic sleep too profound for any possibility of awakening. To arouse this torpid mass, how feeble in action, and how infinitely slow in results, would have been the best efforts of English education, English laws, or even English practical science, as displayed only in the construction of roads and irrigation canals, had not the mighty agency of steam—and more especially of steam locomotion—been called to its assistance. This wonderful vivifying power, scarcely applied, at once commenced its beneficent work, and with a yearly increasing rapidity outstripping imagination, has since continued to quicken the pulse of a whole continent; to infuse a healthy circulation into the stagnant body politic of a vast congeries of peoples; and to urge its rising energies along a new highway of industry, commerce, and material progress, from which it can now never recede.

Nor is it possible to suppose that this mighty upstirring of the various peoples of India will not be accompanied by a general loosening and final casting off of the trammels of superstition, or be unattended with a corresponding moral and religious advancement, in a land from whence, long ages before the infancy of European civilisation, the world had already received some of the most profound conceptions of the human mind; a land which has been the birthplace of an elevated moral and religious philosophy, enriched with many a potent germ, and ready in the more fertile soil of a healthy material progress, and under the influence of an advancing culture, to expand, and assimilate all the ripest products of Western thought. Under the guiding direction of Providence it is from the British nation that the vast continent of India has received the leaven of a new moral

and material regeneration, which can now never cease to operate until it has raised the country to a high level of power and civilisation. The most potent factor in this truly wonderful resurrection of a whole people, so visibly taking place before the eyes of the present generation, is unquestionably the railway system of the country; and there is little reason to doubt that the powerful onward impetus already imparted by railway communication—even if every other instrument of English power were relaxed or removed—would continue to prevail, and that it will ever remain a lasting memorial of the influence of Great Britain on the destinies of India.

It will thus be a matter of no little interest to retrace, even in outline, the main incidents of the rise and early development of Indian railways; but, in order that the reader may intelligently follow the thread of such a narrative, it is first necessary to cast a rapid glance at the principal features of the physical geography of the country. The continent of India is, however, so large and diversified, that in a mere outline description of its physical geography it will only be possible to point out a few of those broad and well-marked features which more specially affect the operations of the railway engineer. India, considered as lying between the mouths of the Ganges and Brahmaputra on the east, the line of the Indus on the west, the Himalayan mountain ranges on the north, and Cape Comorin on the south, has an extreme length of about 1800 miles, an extreme breadth of 1400, and a coast-line of 3600 miles. Geographically, the country is divided into two well-marked natural divisions, differing entirely from each other in physical characteristics, respectively named, 'Hindustan' and the 'Deccan.' Hindustan, comprising the whole northern and north-western portion of the main continent, from the delta of the Ganges to the delta of the Indus, is characteristically a great alluvial plain of only moderate elevation, stretched out immediately at the feet of the Himalayan Mountains. The Deccan, is characteristically an elevated and more or less undulating plateau or tableland, occupying the greater portion of the whole southern extension, below Hindustan, of the Indian peninsula. Hindustan includes a large portion of Bengal

proper, the upper Provinces of the north-west, the Punjab, Scinde, Rajputana, and Guzerat, and extends southwards as far as the main chain of the Vindhyian mountains, a chain stretching from the head of the Bay—or Gulf—of Cambay in a general north-easterly direction, with gradually diminishing altitude, as far as the great southern bend of the Ganges at Rajmahal in Bengal. On the eastern or Bengal side, the great plain country of Hindustan comprises the humid and naturally fertile delta of the Ganges, and its surface is scored with a multitude of river arms, and water-channels, affording easy water communication in almost every direction. The western and north-western side of the great alluvial tract consists for the most part of dry waterless plains, traversed by a comparatively small number of large rivers, some of the most extensive interfluvial regions being practically desert, and all entirely dependent on artificial irrigation for fertility. The principal rivers of Hindustan are the Indus and the Ganges, which, rising in the heart of the Himalayas, and fed by its eternal snows, flow—the first in a general direction, north to south, the second west to east, discharging themselves into the Arabian Sea and the Bay of Bengal respectively at Karachi and Calcutta. Confluent to the Indus are the remaining four great rivers of the Punjab, viz., the Jhelum, the Chenab, the Ravi, and the Sutlej (respectively the 'Hydaspes,' the 'Ascesines,' the 'Hydrazotes,' and the 'Hysudrus' of the Greek invasion). The three principal tributaries of the Ganges are the Jumna, the Gogra, and the Sone. Along the whole northern boundary of the low-lying plains of Hindustan, the triple Himalayan chain of lofty mountains present—and will probably for a long time continue to present—a practically impenetrable barrier to railway extension in their direction.

South of the principal Vindhyian range of lesser mountains, which stretch right across India from the Gulf of Cambay to the Ganges at Rajmahal, the main portion of the peninsula is occupied by the high tableland of the 'Deccan.' This elevated plateau does not, however, for the most part extend to the actual sea-coast. Along the whole western sea-board, from the Tapti river to Cape Comorin, the high land terminates abruptly in steep precipitous slopes and bold rocky bluffs, leaving a low-

lying maritime plain—seldom more than about 30 miles in width—between them and the sea. The edge of the high land, from the Tapti to a gap which breaks through its wall at Palghât, in the neighbourhood of Coimbatore, is called the 'Western *ghâts*,' or 'Syhadree' mountains. The general elevation of its ridge-line does not exceed 3000 feet above the sea, and it is nowhere less than about 2200, but it reaches 5000 feet at Mahableshwar, and 6000 feet in Coorg, to the south of which the Neilgherry range of hills trends inland in the direction of Madras, on the opposite coast. Below the gap at Palghât, the range of *ghâts* extends to the extreme southern point of the peninsula at Cape Comorin. The average breadth of the crest of the Western *ghâts*—presenting a more mountainous character than the general tableland to the eastward—is only about 10 miles, although numerous spurs are here and there projected across the plateau for a further distance of 20 or 30 miles. Towards the southern end, however, the mountainous district reaches 40 miles or more in width. In order to make more plain to the reader the extraordinary nature of the obstacle presented by the line of the Western *ghâts* to the progress of any railway in the direct inland line from the coast, it is necessary to point out that these *ghâts* are not to be considered as a range of hills or mountains *through* which a more or less difficult passage might be found by following the direction of the main valleys on either side, with or without tunnels at the summit, but they consist of what is virtually an almost vertical step, forming a kind of retaining wall to the Deccan high lands; so that a railway attacking them from the west has to climb the face of what is practically a line of sheer precipices, from 2000 to 3000 feet in height, broken only along its front by deep rifts or ravines.

The narrow and low-lying maritime plain situated below the *ghâts*, along the western coast, is occasionally broken by low hills, and is intersected by the estuaries of numerous mountain streams, which descend from the rocky channels and gorges of the high land. From the edge or ridge of the Western *ghâts* the elevated plateau dips away to the east, terminating a short distance before reaching the Bay of Bengal in a line of hills of more gentle contour than those on the west, called the

'Eastern *ghâts.*' The upper tableland is traversed by a number of great rivers, which, rising on the spurs of the *ghâts* on the western side of the peninsula, flow across the whole extent of the plateau, break through the line of Eastern *ghâts*, and descend into the Bay of Bengal. The chief of these rivers are the Kistna, the Godavery, and the Mahanadi, each having many large and important tributaries.

The Vindhyian mountains forming the northern boundary of the Deccan table lands are composed of three distinct chains, viz., the most northern, or 'Aravalli' range of hills—geographically situated in Hindustan—the central or main Vindhyian range, and the southern or Satpura range of lower hills. Between the Aravalli and Vindhyian line of mountains the river Chumbal flows northwards to the Jumna: between the Vindhyian and Satpura ranges the great river Nurbudda flows in a westerly direction to the Gulf of Cambay and the Arabian Sea, whilst rising from neighbouring sources the Sone river flows north and eastwards to the Ganges. The Deccan geographical division of India comprises all the Central Provinces, the greater part of the Bombay Presidency, Hydrabad, Mysore, and the whole of Madras.

Over the vast extent of the great plain country of Northern India or Hindustan, with small exception, the soil is an alluvial deposit of fine sand and clay reaching to an unknown depth. Intermingled with this soil is found immense quantities of *kunka*, a concretion of carbonate of lime and clay, either in the form of hard nodules or in thin beds. This substance, which can be collected with facility, yields when burned an excellent hydraulic lime, admirably adapted for building purposes.

From the points of view of the railway engineer, the most important characteristics of the rivers of Hindustan are their great average size, the immense volumes of water periodically brought down by them during the seasons of flood, the often enormous extent of their inundations, and the erratic and unstable character of their channels. The rivers commonly occupy broad shallow valleys, varying from a mile to 7 or 8 miles in width. These valleys are bounded by low marginal banks of varying breadth, on which the principal towns and

villages are placed. Within the limits of deviation imposed by these more or less permanent banks the rivers at all times wander at will, or sometimes during the season of floods the greater part or the whole of the shallow valley may be filled with turgid water, spilled from the tortuous main channel, which alters its course through the valley from season to season according to the set and wearing action of the current against the light alluvial soil through which it runs. In the lower reaches especially, owing to the heavy annual deposit of silt brought down by the rivers, much of the plain country remote from the banks is at a lower level, and is subject to periodical inundation through the water-courses or *nullas* which intersect the marginal higher ground. The large rivers of the Punjab, flowing through vast level plains of light alluvial deposit are of an exceptionally erratic character; the course taken by their main channels varying over wide limits, so that the works necessary to constrain the body of the stream to preserve a reasonably permanent alignment in the neighbourhood of bridges crossing them, and the net width of waterway to be allowed to such bridges, are among the most difficult problems the railway engineer in Upper India is called upon to solve. Over the higher and more hilly region of the Deccan and south country, with geological formations of greatly diversified character, the more defined catchment basins of the rivers, together with the comparatively fixed and permanent location of their channels, reduces these particular difficulties to more ordinary proportions.

In all countries having free access to the sea, the large commercial ports are among the principal natural centres from which trunk lines of railway will radiate, or the termini towards which they will be directed. This is most markedly illustrated in India, where, notwithstanding its 3600 miles of coast-line, convenient commercial sea-ports are singularly few and scarce. Along the whole extent of the eastern coast, from the head of the Bay of Bengal to Cape Comorin, no really commodious harbour exists. Madras, situated on the eastern coast, is an important railway centre, as the seat of a Presidency Government, but has no natural harbour, and can take but little rank as a commercial seaport. On this side of India the only prac-

ticable port for large ships is Calcutta, situated 100 miles inland on one of the mouths of the Ganges called the Hooghly, through which the navigation is intricate and more or less dangerous. On the western coast the only commercial harbours of any consideration are Bombay and Karachi, of which Bombay is by far the most commodious and extensive. Practically, therefore, the important seaports of India are limited to Calcutta, Bombay, and Karachi, the capabilities of the last being comparatively small, and of recent development.

It was therefore from Bombay, the true commercial capital, and from Calcutta, the political capital of India, that the two first lines of railway, viz., the 'Great Indian Peninsula' and the 'East Indian,' emanated. Both these trunk lines were projected and were commenced at about the same time, although it was a short and easy length of the former that was first opened for public traffic.

It will be obvious, on a first inspection of a map of India, bearing in view the political and commercial importance, and the relative positions of the three Presidency capitals—Calcutta, Bombay, and Madras—that three trunk or main lines of railway will be of primary importance, viz., one from Calcutta, following the general course of the valley of the Ganges, towards Delhi, and onwards to Lahore and the north-western frontier of the Punjab; one from Bombay, meeting the first nearly at right angles somewhere midway between Calcutta and Delhi; and one connecting Madras with Bombay. The two first were, in point of fact, the earliest lines undertaken, and are those which governed the fortunes of the immediately succeeding railways. A rapid sketch of their early history will, therefore, serve to illustrate the story of the introduction of railways into India.

So early as the year 1840 or 1841, projects for extending the benefits of railway communication to India appear to have been discussed by engineers and private capitalists in England, but it was not until two or three years later that the Honourable Court of Directors of the East India Company was approached with any definite proposals. At this time the Government of India was passive, if not actually hostile, to the idea of introducing railways. No doubt the more enlightened minds, both

in India and in England, were fully alive to the advantages certain to accrue to the commerce of the two countries; but it was not conceived possible that the vast amount of capital required could be raised, or that sufficient inducements existed, or could be held out to public investors, which would prevail upon them to embark money upon so visionary and uncertain an enterprise as railways in India. It was assumed that the construction and management of railways could only be undertaken by private enterprise and capital, and that the novelties and unknown difficulties of their introduction into so distant and backward a country, would be sufficient to inspire the general public with certain distrust in the speculation.

In the year 1843, on the invitation—as generally supposed—of the then Governor, Sir George Arthur, Mr. G. T. Clerk, a railway engineer who had been employed on the Great Western Railway in England, went out to Bombay in order to study on the spot the facilities for railway construction from that port to the districts above and beyond the line of Western *ghâts*. In the following year a committee for a railway company was organised in Bombay, having for its object, in the first instance, the construction of a line of railway from the port to the foot of the *ghâts* only, but this inadequate scheme was soon merged in another association having more extended aims, to be named the 'Great Eastern Railway.' Mr. Clerk originally advocated the construction of a line branching off into two lines at Callian, the one surmounting the line of Western *ghâts* to the north-east by the Thull *ghât* towards Candeish, the other passing them to the south-east by the Bhore *ghât*, in the direction of Poona and Madras, on a general alignment almost identical with that—after many intermediate vicissitudes—subsequently adopted. This scheme was warmly supported both by the Governor and the Chamber of Commerce of Bombay, but it failed to meet the approval of a committee of military officers appointed to report on it by the Government of India, it being believed that the obstacle presented by that range of steep and lofty precipices, running parallel with the sea-coast at a distance of about 30 miles inland, called the Western *ghâts*, presented a practically insurmountable barrier to any economical railway construction in the direct easterly

line from Bombay. The 'Great Eastern Railway' scheme for the present, therefore, remained in abeyance.

In the meantime a Mr. Chapman had been busily engaged in England in preparing and advocating the formation of a company for a vast scheme of railway enterprise, intended to embrace the whole of India in its scope. This project, which took the ambitious title of the 'Great India,' or 'Great Indian Peninsula Railway,' was to extend a trunk line due east from Bombay, up the *ghâts*, and right across the peninsula to a harbour at the mouth of the Godavery river on the opposite coast, almost half-way between Calcutta and Madras. Lines of rail were to skirt the coasts, and as soon as the main trunk line had surmounted the *ghâts*, branches were to diverge, one north-east to Allahabad on the Ganges, and one south-east to Madras, from which lines other branches were to ramify practically all over India.

Mr. Chapman, on learning what was being done in Bombay, proposed an amalgamation with the 'Great Eastern Railway' promoters, and eventually the latter association was merged into the 'Great Indian Peninsula' Company, Mr. Clerk being appointed engineer in India. The Bombay committee were, however, naturally adverse to the proposal of a trunk line across the peninsula to the opposite coast, chiefly on the ground that it would be of minimum benefit to Bombay, and that one-half would be a competing line to the other half. In the meantime other promoters, both on the side of Calcutta and Madras, taking the field, the 'Great Indian Peninsula' project, although still adhering to its ambitious name, gradually, by the year 1845, came to restrict its scope to a system designed only to connect with Bombay the principal producing districts situated at a reasonable distance beyond the *ghâts*. These producing districts lay to the north-east and south-east of the port, and any direct lines to them must necessarily bifurcate below the *ghâts*, and mount them by two separate ascents, but these *ghât* ascents involved stupendous engineering difficulties, and the great body of the promoters were prepared to sacrifice directness in favour of one central ascent, to be situated at the Malsej *ghât*, with a bifurcation somewhere above instead of below the line of *ghâts*. Later and more detailed investigation,

however, led to an abandonment of this idea, and a reversion to the original design of the 'Great Eastern' scheme, viz., two separate *ghât* ascents, one to the north-east and one to the south-east of Bombay, which, as we shall see in the following chapter, was the course eventually adopted and carried out.

It was from the early 'Great India' or 'Great Indian Peninsula' Company—the promoters of the visionary scheme of constructing a main trunk line of railway right across the peninsula from Bombay to Caringah, at the mouth of the Godavery river —that the first suggestion for a Government guarantee appears to have emanated. In November of the year 1844, through their agents in India, these promoters proposed that, in order to stimulate the ardour of those persons seeking safe investments at moderate rates of interest, the Government of India should offer a guarantee of 4 per cent. from the date of opening the railway, or any portion of it, with a proviso that if the profits exceeded 10 per cent. the surplus should be devoted to a fund expressly appropriated to a further extension of the lines under the company—extensions subject in their turn to a similar guarantee. The duration of the arrangement was to be limited to some term of years to be agreed upon. It is needless to say that these proposals did not meet with acceptance, but among the numerous railway promoters, who had by this time begun to turn their attention to an Indian field of operations, it was very early seen that there would be little probability of raising in the public market any capital adequate for the purposes of railway enterprise in India, unless the Honourable East India Company were willing to offer some kind of security for the money advanced. Among the lines mooted at the very earliest date was one which took the name of the 'East Indian Railway,' having for its object the construction of a line starting from Calcutta and following the Mirzapore road for a distance of 140 miles towards Allahabad—Mr., afterwards Sir Donald, Stephenson, being the principal promoter. At the end of the year 1844 the managing director of this proposed Company suggested that, in order to encourage the introduction of railways into India, the Government should adopt a plan then working successfully in France, and guarantee a minimum dividend to the railway shareholders from the date of opening the line for

traffic. Negotiations were opened on this basis. The company proposed a guarantee of 4, subsequently lowered to 3, per cent. on a capital expenditure which was not to exceed one million sterling, or an annual bonus of £30,000 until the profits should reach 3 per cent. Soon, however, the important modification was introduced, that the interest should be guaranteed from the commencement of operations, instead of from the date of opening for traffic. The Honourable Court of Directors, after due consideration of these, together with the various proposals made by other nascent companies, addressed an important despatch to the Governor-General in India, calling attention to the whole question of the introduction of railways into that country.

This despatch, dated 7th May 1845, is interesting as being the first official recognition of the desirableness of railways for India. It contains, moreover, some curious assumptions which have been signally falsified by the event, and apprehensions of peculiar difficulties in railway construction which have not in practice been seriously experienced. It was assumed, on grounds which probably few at that time could have called in question, that, contrary to the experience which had been already gained in England and Europe, the 'remuneration from railroads in India must for the present be drawn chiefly from the conveyance of merchandise, and not from passengers.' It was apprehended that, in addition to the ordinary difficulties common to railroads in all countries, there were others peculiar to India which would be almost insuperable, such as the violence of the periodical rains and inundations, the continued action of violent winds, and the influences of extreme heat; the ravages of insects and vermin, and the destructive effects of spontaneous vegetation on timber, earthworks, and masonry; the unenclosed and unprotected nature of the tracts of country traversed, and the difficulty and expense of securing the services of competent engineers and engine-drivers. In view of these considerations —of no small weight in the year 1845—the despatch from the Court of Directors was soon followed by the deputation from England of an experienced civil engineer, who was selected as especially conversant with railway questions and requirements. The gentleman selected was Mr. Simms, C.E., who arrived in

Calcutta in September 1845. He was instructed to examine into the whole question of the applicability of railways for India in all its bearings, and it was directed that two competent military engineer officers, to be appointed by the Government of India, should be associated with him, and the committee thus formed were to investigate and report on the whole matter, and to suggest some moderate and convenient length of line which might be undertaken as a sort of experiment. The directors also made certain general suggestions with regard to the nature of the control to be exercised by Government over any railways that might be intrusted to the agency of private capitalists, or companies, and recommended these suggestions for consideration and comment.

In February 1846, Mr. Simms drew up a set of proposed stipulations for the main clauses of contract between the Government and private railway companies. In return for certain concessions to be made by the former, the principal of which was the very moderate one of a free grant of land, companies were to be subject to a most complete and minute government regulation and control, and at the expiration of a lease of certain definite duration, the railway, in perfect order and repair, was to be handed over to the Government without payment. In addition Mr. Simms suggested that, if thought advisable, a small percentage might be guaranteed on the actual capital cost of the works from the date of opening for traffic.

In the same month the committee of engineers submitted their report on the general applicability of railroads to the conditions and circumstances of India, and on the apprehended peculiar climatic and other difficulties, which they had been invited to consider. On the general question, the committee was of opinion that railways, far from being inapplicable, were, on the contrary, quite capable of being constructed and maintained in India, as perfectly as in any part of Europe, and, moreover, that their introduction was a great desideratum. With regard to the apprehended peculiar difficulties enumerated by the Court of Directors, they admit their existence in some degree, but regard them as easily surmountable. Seriatim, each item is gravely discussed, and it is quietly enunciated, possibly with some satire, that suitable arrangements in the

construction of the works will overcome any difficulty likely to arise from these causes to the line itself, nor do they consider them to be of a nature to prevent an immediate prosecution of railway enterprise.

The committee in a long and—considering the extreme paucity of data existent at that time—very able report, recommend the introduction of railways into India by the agency of private companies, and advocate the construction of a line following a direct route from Calcutta to Mirzapore, and thence to Delhi, with various lateral branches. If a short experimental line is considered necessary, they advise one between two important centres, such as Cawnpore and Allahabad, or a shorter line between Calcutta and Barrackpore. The committee in their report did not enter into the question of the cost of construction of railways, or the probable remuneration, but somewhat later, on being pressed for their opinion on these points, reported £14,000 to £15,000 per mile, without rolling stock, as the probable initial outlay—an estimate not very far from the truth for the earlier broad-gauge lines; but they declined to give an opinion on the probable returns, being entirely without data on which to base an estimate.

Mr. Simms' suggestions for contract with railway companies, and the report of the engineering committee, were then taken into consideration by the Government of India. Lord Hardinge, the Governor-General, was at the time absent from Calcutta, the question was, therefore, discussed by the president (Sir Herbert Mallock) and members of council. The proposal that Government should provide land free of cost was unanimously approved. In view of this concession it was not considered necessary that any guarantee of interest should be offered, but all the members were, nevertheless, agreed in the opinion that the fullest powers of directing the construction, and controlling the management, of all railways should remain with the Government. Mr. Simms' proposal that railway companies should deliver over at the termination of their lease the whole railway, free of cost, was objected to on the obvious ground that it was highly improbable that any projectors would agree to such an arrangement; it was considered quite sufficient to secure to Government the option of purchase on settled terms at the end

of a certain period. Finally, as the conclusion of an elaborate and forcible minute on the whole question, the president and council considered that a long length of line from Calcutta to Delhi should be chosen as the first line to be encouraged, and that if an experimental length of railway was deemed necessary at all, it should be one between Calcutta and Burdwan, with a branch to Rajmahal on the Ganges.

In July 1846 the Governor-General recorded his own views in a brief but statesmanlike minute. Lord Hardinge was disposed to grant far more substantial encouragement to railway enterprise than were the president and members of his council. He pointed out that a lease of land representing a contribution roughly estimated at £200 a mile, to a work calculated to cost £14,000 a mile, was totally inadequate, and he expressed his conviction that 'the speculation of the railway company (*i.e.* the proposed "East Indian") will entirely fail, unless it be largely and liberally encouraged by the East India Company.' Enumerating the advantages and economy to Government of a daily mail service between Calcutta and Delhi, and the important military aspects of the question, he gave, in conclusion, his opinion that 'on military considerations alone the grant of one million sterling, or an annual contribution of five lakhs of rupees, may be contributed to the great line when completed from Calcutta to Delhi, and a pecuniary saving be effected by a diminution of military establishments.' The Governor-General, in fact, thoroughly realised that, without some really large and substantial assistance, it would be impossible for joint-stock companies to raise the capital necessary to construct the great railroads of India, although he was rightly opposed to the principle of granting such aid until the period of completion of the works.

The various opinions and reports of the authorities in India were now referred to England, and from that date commenced a long and weary triangular duel of negotiation between the promoters of the companies and the Honourable Court of Directors in London, and between the latter and the Commissioners for the affairs of India, or Board of Control. These negotiations and discussions were protracted over a period of about three years, a delay which appears to have been almost entirely

chargeable to the parsimonious views and difficulties raised by the Board of Control. In the final result of the struggle, during which, on more than one occasion, the negotiations almost completely collapsed, the companies practically obtained all the concessions for which they had so long contended, viz., an absolute guarantee of 5 per cent. on all sums authorised to be paid into the treasury of the East India Company, so long as they held ownership of the railways, and repayment of the actual capital expended on the lines, plant, and rolling stock, at any time they pleased, on giving six months' notice of surrender. A general understanding having been at length arrived at, preliminary legal agreements were signed with the 'East Indian' and 'Great Indian Peninsula' Railway Companies on the 17th August 1849. The final terms of the contracts some time subsequently entered into under the much abused 'guarantee system,' between the Government of India and the railway companies, may be thus briefly summarised.

1. 'The design and execution of certain railroads in India are intrusted to joint-stock companies.'

2. 'The Indian Government guarantee interest on moneys duly raised by companies and paid over to Government, controlling at the same time their expenditure and operations.'

The interest guaranteed was from 4½ to 5 per cent. for ninety-nine years, on all money paid with authority into the Government Treasury. An option was given to the railway companies to demand repayment, on six months' notice of their intention to surrender the railway, of the whole capital duly expended by them. The Government also agreed to 'leave to the railway company, free of cost for ninety-nine years, all land required for the permanent works of the railway, and further to provide all other land temporarily needed for its construction.' In return for these important and valuable concessions, the Government retained power to supervise and control the whole of the affairs, operations, and expenditure of the companies, whether in India or in England; they obtained the free carriage of mails, and the carriage of troops and military stores on favourable terms, and the power of appointing a Government director to sit at the boards of railway companies in England, having a veto on all their proceedings, except certain privileged

communication with legal advisers. All receipts from traffic were to be paid into the Government treasury, and all profits above the guaranteed interest were to be divided equally between the Government and the shareholders, until the debt of the railway company for guaranteed interest was repaid, after which all profits were to accrue to the shareholders. Powers to surrender by the Company, and powers of purchase by the Government, or to take possession in case of failure of agreement, were also given, and the money transactions between the contracting parties were to be calculated at the rate of 1s. 10d. per rupee.[1]

These terms, highly favourable as they undoubtedly were to the companies, naturally removed all difficulty in obtaining almost unlimited funds for the purposes of railway construction; and in spite of much that can be urged against them under the results of practical working, they have had the effect of conferring on India the inestimable indirect benefits of railway communication, and inaugurating her career of material prosperity from a much earlier date than could have been effected by any other means.

[1] The rate was varied in other contracts.

CHAPTER VII

INTRODUCTION OF RAILWAYS INTO INDIA

Introduction of railways into India (*continued*)—Commencement of railway construction—Slow progress—Causes of delays—Discussions on fundamental principles—Novel theories—Report and proposals by Colonel Kennedy, R.E.—Proposed regulations—Ruling gradients and limitation of cost—Coast and valley lines—Long discussions—Suspended system of railways—Lord Dalhousie's exhaustive minute—Sanction accorded to line from Calcutta to Delhi—Western *ghât* surveys ordered—Era of Indian railways begun—Studies for the *ghât* ascents from Bombay—Final approval of the Bhore and Thul *ghât* proposals—Main route followed by the Great Indian Peninsula Railway—The East Indian Railway—Experimental length of line—Position of Calcutta—The Hooghly—Determination of the question of standard gauge—Principal standard dimensions fixed—Government control—Consulting engineers appointed—Large powers exercised—Vexatious delays—Parliamentary committee—Beneficial effect of report—Principal features of the Government control—East Indian Railway—Early proposals and particulars—The Madras Railway Company—Early history and initiation.

Introduction of Railways into India.

We have seen that the 'East Indian Railway' emanating from Calcutta, and the 'Great Indian Peninsula Railway' from Bombay were projected and organised at about the same time. Construction work on the section from Bombay to Callian—33 miles in length—was commenced in February 1851 as an 'experimental' line; and a portion of this section, 20 miles in length, from Bombay to Tanna, was opened on the 16th April 1853, about a year and a half before the opening of the first 37-mile 'experimental' section of the 'East Indian Railway' from Calcutta to Pandua.

Rapidity, in the early construction of railways in a new country situated as India was forty years ago, was hardly to be expected. Practically nothing in the way of manufactured materials or working plant was purchasable in the country; and the engineers or contractors had to manufacture, prepare

or collect—often from great distances—everything required, such as bricks, stone, lime, timber, iron-work, or plant of all kinds. At the commencement of operations, and for some time subsequently, no trained subordinate staff existed, and inspectors imported from England—then a vastly more distant country than at present—were almost useless until they had acquired some knowledge of the language, and had learned and unlearned much new and old experience; and lastly, skilled labour of almost every description did not exist, until in course of time it could be trained and educated, and even ordinary unskilled labour was difficult to secure, until full confidence in the new employers had been gained.

Much delay was also entailed by the natural hesitation of the chief Government authorities amidst the conflicting views of responsible advisers, and the opening up anew of lengthy discussions on fundamental principles, whether as guiding the choice of route for the railways, or the actual details of construction; principles, the greater number of which had already been threshed out in the twenty years' experience of practical railway engineers in Europe, but which were more or less unfamiliar to many of the military engineer officers in high authority in India, who necessarily approached the subject from an almost purely theoretical standpoint.

That some mistakes should have been made was only what might have been anticipated; but that errors of judgment should have been on the whole so few, and that they should have entailed so little ultimate loss beyond some unnecessary delays, is a remarkable evidence of the care and skill with which the many large-scaled problems presented by Indian railways, were from the commencement met and overcome. Amongst the most prominent of the many elaborate and startling theories broached on the eve of Indian railway construction, was one which emanated from Colonel Kennedy, R.E., for a short time Consulting Engineer to the Government of India for Railways, and subsequently Consulting Engineer to the Bombay and Baroda Railway Company. In a report or memorandum written at the close of the year 1851, addressed to the Honourable Court of Directors, Colonel Kennedy drew up a kind of code of rules and regulations for the

proposed guidance of railway authorities in India, containing some essentially novel views and opinions, which, coming from a man in his prominent position, necessarily demanded attention and careful consideration. Dealing first with the military and economical aspects of the question of railways in India, Colonel Kennedy proceeded, in twelve proposed regulations, to lay down the broad general principles on which the whole railway system of the country ought, in his opinion, to be guided, and, in unsparing language, he condemned all that had hitherto been done by railway engineers.

In opposition to the contemplated direct route of the 'East Indian Railway' from Calcutta to Mirzapore, passing through the Shergotty range of hills, and the ascent of the line of Western *ghâts* by the proposed 'Great Indian Peninsula Railway' from Bombay, he argued in favour of a sort of Median and Persian Government decree, that no trunk line of railway in India should have a ruling gradient of more than 1 foot in every 2000 feet, or 1 in 330 on secondary or branch lines; that no line should be undertaken which was estimated to cost more than £5000 a mile, exclusive of bridging the larger rivers; and in order to secure the necessary flat gradients, and on the hasty assumption that the rivers of the country were everywhere the main arteries of commerce, he proposed that lines of railway should be constructed skirting the whole coast line of India, and thence be carried all over the interior of the country by closely following the lines of the great river valleys. Thus the line of the 'East Indian Railway' should closely follow the course of the Ganges from Calcutta, *viâ* the great bend at Rajmahal; and the line of the 'Great Indian Peninsula Railway' from Bombay, instead of recklessly ascending the Western *ghâts* on a necessarily steep and most expensive alignment, should follow the natural routes to the interior —on the north, *viâ* the coast line and the Tapti and Nurbudda valleys; and on the south to Madras, *viâ* the coast, the gap in the *ghâts* near Coimbatore, and the Kaveri valley to the eastern coast line.

In the long discussions which followed this celebrated memorandum it was ultimately agreed that no such gradients as those proposed for the trunk lines were economically feasible,

even by following the course of the river valleys; that it was better, in most cases, to construct a line with steep gradients than no railway at all; that the cost of the increased length of line necessary to secure such flat gradients would be greater than the cost of working the steeper grades, *i.e.* that a short line with steep grades might in the majority of cases be a cheaper line to work as well as to construct, than a longer one with easier gradients. It was also seen, that to limit the estimated cost of railways per mile to any rigidly fixed sum, and that a sum altogether inadequate, would be not only impracticable but extremely injudicious. With regard to the recommended coast and river valley scheme of railways for all India, it was opposed, that not only would the coast lines cross the whole drainage of the country at its largest point, and be the most expensive to construct, but would also commercially and politically be the most useless, and everywhere in direct competition with sea-borne traffic. It was shown that in every country it is necessary that railways should be laid out with reference to the distribution of population, and to the general resources and necessities of the people, rather than to the mere physical characteristics of its geography, and with reference to the greatest political and commercial advantages, than with a mere view to easy gradients, however desirable these might be when readily obtainable. Moreover, the idea that the great river valleys were necessarily the main arteries of commerce, was in India—except in a few instances—shown to be peculiarly erroneous, and that an attempt to lay down *any* inflexible and rigid system of railways to cover the whole face of the continent was both premature and unpractical.

Belonging to an entirely different category, and as a mere curiosity, may also be mentioned the appearance—shortly after Colonel Kennedy's noted memorandum—of a book written by a Colonel Grant, of the Bombay Engineers, to prove that the idea of laying down the permanent way of railways on the surface of the ground was utterly inapplicable under the conditions and circumstances of India. He recommended, with all seriousness, that every Indian railway should be suspended throughout its entire length by a regular series of suspension chains, at a minimum height of 8 feet above the ground, which

he considered would be ample to place it above the reach of animals. Costly models of this unique system of railways were even prepared and exhibited. Several other theories of equally ingenious and erratic character had to be combated by the infant railway system of India, much as the human child has to undergo its regular course of infantile maladies.

The twelve general rules and principles advocated by Colonel Kennedy, although in their most essential features not adopted, had nevertheless, the advantageous result of compelling the close attention of the Government authorities to many matters of the highest importance in connection with the first location and construction of railways on a new and virgin soil, and in this manner may possibly have hastened the arrival at precise and definite conclusions respecting them. In the early part of the year 1853, Lord Dalhousie, then Governor-General of India, after having received the reports and opinions of all the various consulting engineers and railway experts in the country, reviewed in a masterly minute, at once clear and exhaustive, the whole question of railway routes for the earlier trunk lines, and the guiding principles to be adopted on all the main points of controversy which had been so long under discussion. The recommendations formulated in this peculiarly lucid statement, which have rendered it a justly celebrated document in the history of Indian railways, were at once fully concurred in by the Honourable Court of Directors in London, who were now thoroughly alive to the vast benefits certain to ensue from the construction of an extensive and well-planned system of railway communication in India, carried out in a large and liberal spirit. They accordingly, without hesitation, gave their assent to the immediate commencement of a line from Calcutta by the Ganges valley to Delhi. With regard to the railway from Bombay, they directed that surveys for the several *ghât* routes proposed should be at once undertaken, and they expressed their willingness to sanction the prosecution of a line from Madras to Bombay *viâ* Cuddapah and Bellary, as well as certain other proposed lines, should the result of the surveys prove satisfactory.

From this date, viz., the latter end of the year 1853, the era of Indian railways may be considered as really begun. The

line of the 'East Indian,' from Calcutta towards the Upper Provinces, was fairly launched on its long journey. The 'Great Indian Peninsula' had opened its first section of iron-road to Tannah, in the direction of Callian and the *ghâts*, and the minds of all those responsible for the interests and well-being of India had now fully recognised the importance as well as the practicability of an extended system of railways in that country, and were actively engaged in the solution of its many initial problems. The infant line from Bombay had, however, stopped short at the foot of stupendous difficulties, and had yet to pass through some period of painful struggle before the path of its further progress could be cleared.

Mr. Clerk, who, as we have seen, ten years before, when working in connection with the then-called 'Great Eastern Railway,' had advocated the surmounting of the Western *ghâts* by two routes, in the main identical with those subsequently adopted, appears, on detailed investigation, to have been daunted by the formidable character of the difficulties his proposals would involve. In the year 1847, we find him arrived at the conclusion that the Thull and Bhore *ghâts* were virtually impracticable for railway purposes, and advocating in their stead a single passage at a point situated about mid-way between the two, by a route known as the Malsej *ghât*, with a bifurcation of the line at some point *above*, instead of *below* the line of *ghâts*. This route was the one at first contemplated by the 'Great Indian Peninsula Railway' Company, into which the 'Great Eastern' had in the meantime merged, and was, moreover, the one generally agreed to by Government, and was incorporated in the first agreement entered into with the company in 1849.

In the year 1850, Mr. James Berkeley, C.E., who was appointed chief engineer to the company, entered upon a detailed examination of the Malsej *ghât* route, and soon came to the conclusion that the difficulties of carrying a railway by that line were practically insuperable, and that on commercial grounds it would be injudicious; he, therefore, turned his attention to the abandoned routes *viâ* the Thull and Bhore *ghâts*. These *ghâts*—the first to the north-east, the second to the south-east of Bombay—were each already occupied by

ordinary roads. In the early part of the century, under the orders of the great Duke of Wellington, a track, passable by artillery, had been formed up the Bhore *ghât*, leading towards Poona, and in the year 1830 this track had been re-made, and improved into a cart-road, which was still in use as a trade route to the Deccan. Under the orders of the Bombay Government, a few years before the era of railways, an excellent road for wheeled vehicles had also been carried up the Thull *ghât*, and this road was now used for the mails, and formed the only serviceable trade route to the districts of Candeish. By the year 1852, Mr. Berkeley had traced and laid out a series of inclines by both these *ghâts*, which promised an eventual alignment for the railway, which, although severe, would be suitable for locomotives. In view, however, of the enormous difficulties that would in any case be involved, and more especially owing to the whole question of economical railway construction having been opened up by Colonel Kennedy's memorandum, the Government of India hesitated to commit itself to a definite decision as to the best north-eastern route to be followed by the Great Indian Peninsula trunk line, until further exhaustive studies and surveys were made, or until it was clearly proved that the route *viâ* the coast and the Tapti valley to Candeish—enabling the *ghât* ascent to be avoided altogether—was economically undesirable. With regard to the south-eastern route towards Poona and Madras, it was acknowledged that some *ghât* ascent was inevitable, but it was directed that further search should be made to discover, if possible, an easier route than that by the Bhore *ghât*. These instructions having been received, active steps to prosecute the surveys ordered were at once taken.

During their prosecution, however, the chief engineer of the Great Indian Peninsula Railway continued with unremitting care and industry his study of the Thull and Bhore *ghât* inclines. His survey of the proposed Tapti valley route enabled him to demonstrate, first, that it would, to the same fixed point in Candeish, require 131 miles of additional railway, and that it would cost over a million sterling more to execute than that *viâ* the Thull *ghât*, besides the saving in time, working expenses, and the additional profits ensured by the shorter

alignment, which, moreover, had the advantage of following the existing and natural trade route. He showed, also, that a perfectly practicable series of inclines suitable for locomotives was obtainable both by the Thull and Bhore *ghâts*, and that as all the heavy goods traffic from the Deccan districts would be in the downward direction towards Bombay, the *ghât* inclines would be in favour, rather than adverse, to the working of the line.

It was not, however, until the end of the year 1854 that all objection to the Bhore *ghât* route was withdrawn, and until the following year that the Thull *ghât* proposals were agreed to, the approval of the Honourable Court of Directors to the latter not being recorded until the 31st January 1856, by which time it was finally decided to proceed with both these prodigious engineering undertakings. It will thus be seen that a very considerable period of time was expended in a thorough examination and investigation of the Syhadree range. Whatever portion of this long delay may be fairly debited to the hesitation of the Government, Bombay at least had the satisfaction of knowing that no exertions had been spared to prove that the earlier decisions arrived at by the company's engineers were thoroughly sound and practical.

The ultimate main line routes followed by the Great Indian Peninsula Railway are as follows. Proceeding across the marsh separating the island of Bombay from the island of Salsette, and across the arm of the sea separating the latter from the mainland of the Concan, the early experimental line, 33¼ miles in length, which was completed and opened for traffic in 1854, arrives at Callian. From Callian two lines diverge—one north-east, surmounts the Thull *ghât*, and proceeds to Bhusaval, from whence again two lines diverge, one extending to Jubbulpore, where it joins a branch of the East Indian Railway from Allahabad, and one to Nagpur, the capital of the Central Provinces. The second line diverging from Callian, mounts to the Deccan high lands by the Bhore *ghât*, and proceeds to Poona, Sholapore, and Raichore, where it joins the Madras Railway. The total length of the Great Indian Peninsula system is 1288¼ miles. In the year 1863, or ten years after the opening of the first section to Tanna,

552 miles were open for traffic, and by the year 1870 the system was complete approximately to its present dimensions.

It is now necessary to turn our attention to the fortunes of the 'East Indian' Railway, starting from Calcutta. We have seen that a preliminary agreement was entered into with this company on the 17th August 1849, but that it was not until the latter part of the year 1853—after Lord Dalhousie's celebrated minute—that the Honourable Court of Directors gave their final and unhesitating assent to the construction of the line the whole way to Delhi. In accordance with the early idea that it would be desirable, in the first instance, to construct a short length of railway in Bengal for the purposes of experiment (an idea also extended to each of the other Presidencies), the length from Calcutta to Burdwan, with a branch to Rajmahal on the Ganges, had been recommended as a suitable one for the purpose. On the signing of the agreement in 1849, it was proposed to construct a single line to Raneegunge, a point about 120 miles from Calcutta, situated near the coal-fields a short distance beyond Burdwan, and on the line of direct route towards Mirzapore and Delhi; the object being the opening up of this rich mineral district. In July 1850, Lord Dalhousie sanctioned the construction of the experimental line as far as Pandua, 37 miles in length, with works for a double line of rails, and recommended its extension to the Raneegunge coal-fields. In the same year the detailed surveys were put in hand, and the first section of land was made over in January 1851, when construction work on the experimental line actually commenced.

The capital city of India is situated on the *left* bank of the Hooghly tidal-channel, and any line of railway starting from it in the direction of Burdwan and Delhi would immediately have to cross this channel, an obstacle of considerable magnitude. Opposite Calcutta the Hooghly has a stream some 1700 feet broad, with a maximum depth of 40 feet below low-water, a tidal rise of 20 feet, with a very rapid flood velocity, and unusual difficulties in the formation of convenient railway approaches. It is probable that if capital had from the beginning been raised for the construction of the whole long length of 1017 miles to Delhi, the advantages of locating the terminus

of the line on the Calcutta side of the Hooghly would have overweighed the large, although in this case relatively small, expense of erecting a bridge over that channel, but for the purposes of a short experimental length of line with a capital of a million pounds only, it was plainly inadmissible; so that after some discussion of alternative proposals it was decided to commence the railway at Howrah, a suburb of Calcutta, situated on the right bank of the Hooghly opposite the city, communication being maintained by means of a steam ferry.

It became necessary somewhat before this time to finally decide upon the important question of standard gauge to be adopted for Indian railways. Mr. Simms, the consulting engineer to the Government of India, sent out by the Court of Directors in 1845, is said to have been the author of the 5 feet 6-inch gauge actually adopted, and it is probable that this particular width was selected merely as a convenient mean between the ordinary 4 feet 8½-inch and the 7 feet gauges then in use in England, and as a dimension giving more space for locomotive machinery and admitting more comfort in passenger carriages, than it was thought could be conveniently attained on the ordinary narrow gauge. The full bearings of the question of width of gauge for railways was at this early period imperfectly apprehended, and the decision arrived at was undoubtedly an unfortunate one, since there can be little question that, had the now fixed English standard been at first adopted, the railway system of India would have been spared whatever disadvantages have arisen from its present want of uniformity of gauge.

In the year 1856 the principal standard dimensions of roadway and rolling stock to be henceforth adopted, and strictly adhered to on Indian railway lines of the 5 feet 6-inch gauge, was definitely fixed by mutual agreement among the consulting engineers to each of the Indian railway companies, and was approved by Government. The extreme importance of a rigid uniformity in this respect, the want of proper attention to which had already occasioned, and still continues to occasion, much inconvenience on English railways, was thus early recognised in India, and the same principle of strict adherence to well-formulated standard dimensions, was also observed in the

case of the narrow-gauge lines subsequently introduced. As a consequence of this timely forethought, there is now probably no large system of railways in the world superior to that of India in respect of this important matter. The leading dimensions for railways of the 5 feet 6-inch gauge, fixed in the year 1856, were as follows :—

	Ft.	Ins.
Minimum clear width between two tracks, . .	6	0
Minimum distance of platform-wall from rail, . .	2	6
Projection of nosing not to exceed . . .	0	3
Minimum clear height for all openings above rail in centre of each line, ...	14	6
Breadth from centre to centre of buffers, . .	6	5
Height of centre of buffers above rail-surface, . .	3	6
Extreme width of body of passenger-carriage, . .	8	6
,, ,, roof ,, ,, . .	8	10
,, ,, steps ,, ,, . .	10	0
Maximum length between centres of wheels (all vehicles)	11	0
Minimum diameter of turn-tables, . .	15	0
,, ,, of engine-tables, . .	40	0

Detailed lists and diagrams of maximum and minimum dimensions for all fixed structures, both inside and outside station limits, and of rolling stock, were also elaborated at a very early period, and have since been strictly enforced by the consulting engineers to Government for railways.

It has been shown, that from the earliest inception of railways for India, both the Honourable Court of Directors and the Indian authorities were thoroughly alive, not only to the importance but to the absolute necessity of retaining in the hands of the Government of the country, the fullest powers of control over all the proceedings and operations of the joint-stock companies proposing to undertake the construction of railways. Under the contracts entered into with the companies, and in exchange for the liberal terms offered, the Government, in fact, secured this control to an almost unlimited extent, whether as regards the supervision, expenditure, and staff of the companies during the construction of the lines, or after their opening for traffic. In England, as we have seen, a Government director was appointed to sit on the board of guaranteed railway companies, having a veto on all their proceedings, except certain

privileged communications with legal advisers. In India, the large powers of control admitted by the contracts were at first exercised directly by the Government acting on the advice of a specially appointed consulting engineer conversant with railway practice, but as the multitudinous business connected with the early lines increased, and the constant reference of matters of detail to the supreme government became needlessly cumbrous, separate consulting engineers were appointed to each local government, and subsequently to special railway divisions, intrusted with large discretionary powers, which, however, they exercised under general rules and regulations laid down for their guidance. These rules and regulations were supplemented as need arose from time to time, and it was laid down that certain matters of general importance were to be specially referred to the Government of India for decision.

The officers appointed for the discharge of these important functions, requiring in their dealings with the officials of the companies, great tact, judgment, and professsional ability, were for the most part, or entirely, selected from the corps of Royal Engineers. The system when at first established seems, as might be expected, to have worked with some degree of friction. Relative responsibility was, in fact, very ill defined. In constructional matters all initiation, both of design and estimate of works, was in the hands of the engineers of the railway; but these could execute nothing without the express approval of the Government officers, on whom, without any powers of origination of their own, was thrown a very large responsibility. The consulting engineers, themselves the agents of a higher authority, could obviously act only on reasonably full and detailed information, not always forthcoming in the particular shape demanded, and it could hardly be otherwise but that the procedure at starting should in some cases have led to vexations and delays, responsibility for which both sides considered themselves in a position to repudiate. The Government consulting officers in the early days of railways, although often men of great judgment and administrative ability, were rarely equal to the companys' engineers in practical experience of constructional details, whilst the latter were probably unduly impatient of a control and criticism, and of opinions which,

rightly or wrongly, they supposed to be frequently based on too purely theoretical grounds.

In the year 1857-58, a parliamentary committee was appointed to inquire into the causes of some delays which were alleged to have occurred in the prosecution of railway enterprise in India, and the whole subject of the special machinery for the exercise of the large powers of Government control given by the contracts was incidentally, but most carefully, at the same time, gone into. With regard to this particular detail of the inquiry, the substance of the report of the committee was, *that* up to that time the progress of railways under construction in India bore favourable comparison with that of English lines, *that* willing testimony had been given by many of the railway authorities themselves to the value of the Government control to the interests of the companies, when rationally and temperately used, and that 'if due care was taken to intrust discretionary power only to men who are to be relied on as competent to distinguish an effective general control, from too great an interference in details, by a judicious adherence to the spirit rather than the letter of the contracts,' the committee was assured 'that the arrangements might be simplified, united action for one common object secured, and railway enterprise in India may before long assume proportions commensurate with the vast commercial, agricultural, and mineral resources of that country.'

This report had an immediate beneficial effect, and brought about not only a more patient acceptance by the companies of the conditions imposed by the contract terms, but helped to promote a greater mutual confidence and respect for opinion on both sides. The companies' officers, as time went on, were led to comply more strictly with the reasonable requirements of the consulting engineers in respect of the fuller and more detailed preparation of designs and estimates prior to submission for approval, and the latter, soon gaining a wider practical experience of the detailed construction and working of railways, were induced to exercise their large powers in a broad and liberal spirit.

The control exercised in India by the consulting engineers to Government for railways over the whole expenditure and

operations of the guaranteed companies, has undoubtedly had the most beneficial results in safeguarding the general interests of the Indian public, and securing, at the same time, the ultimate interests of the railway shareholders themselves; and in consequence of the almost absolute nature of the control exercised from the commencement by one central governing authority, the Indian railway system, considered as a whole, has been spared many of the now almost incurable evils which, especially in England and America, has resulted from the enormous powers which have been allowed to fall into the hands of the great railway corporations.

In relation to the construction of the guaranteed lines of railway, the principal features of the control exercised by the Indian Government, either directly or through their consulting engineers, may be thus briefly summarised: The final decision as to the direction and course to be taken by the railways, the position of all the more important stations, and other large works. The preliminary approval of all designs, estimates, and indents whatsoever, whether for works or establishments. In the case of completed lines, the absolute control over all capital expenditure, and powers of supervision and regulation of every detail of engineering expenditure or traffic-working of the railway. Special powers are also conferred on the consulting engineers for Indian railways to examine into and report on all cases of accident and injury, whether to life or property, within the railway boundaries. To minutely inspect in the closest detail, every half year, the working condition of every line of railway in their special circle of authority, and report on all matters requiring attention, whether as regards the safety of the line or passengers, the convenience of the public, or the well-being of the company's staff. To inspect, prior to opening for passenger traffic, every new line of railway, or additions to older lines, and to subject at any time to such tests as may be deemed necessary the strength and stability of all bridges, whether permanent or temporary, whether new or old.

It is now necessary to return to the East Indian Railway. The construction of the experimental line, 120 miles long, through Burdwan to the Raneegunge coal-fields, encountered to the full all those ordinary difficulties and delays inseparable

from the initiation of large and novel engineering operations in a new country; but in addition, the rapid prosecution of the works was greatly affected by the refusal of large and competent contractors to undertake contracts on the terms at that time held reasonable by the governing authorities. The works were therefore, for the most part, let to a number of small and inexperienced local contractors, under agreements which were also, perhaps, somewhat hastily entered into. It was not, consequently, until September 1854, or at the end of 3 years and 9 months from the commencement of the works, that the first section of the experimental line from Howrah to Pandua, 37 miles in length, was opened for public traffic, or until February 1855 that the whole 120 miles to a point near Raneegunge coal-fields was completed and opened.

During the course of this interval the original contract with the 'East Indian Railway Company' for the experimental line, had been superseded by a larger one for the construction of a railroad the whole way to Delhi. The original proposal of the company had been to construct a main line from Calcutta by the direct route to Mirzapore, passing through the Shergotty hills and on to Delhi, with branches to Rajmahal, Patna, and Benares, thus avoiding altogether the Ganges valley east of Mirzapore. Owing principally, however, to Colonel Kennedy's powerful advocacy of river valley routes and flat gradients at this time, and partly on local commercial considerations, the alignment eventually chosen for the main line was that *viâ* the Ganges valley, from Burdwan, through Rajmahal and Patna, a decision which, when later it became a question of doubling the track on this route, led to the construction, as a preferable alternative, of a chord line, with double line of rails passing over a part of the hilly districts, in order to shorten by 64 miles the total length of the through route to the Upper Provinces, and to traverse a valuable coal district. It is probable also that, to still further shorten the through route, the originally projected alignment through the Shergotty hills will eventually be constructed.

The length of the extension from Burdwan to Delhi by the Ganges valley, or loop line, first decided upon, was 930 miles, and the contract with the company for its construction was

signed on the 15th February 1854; but some time before this date preliminary sanction to the acquisition of land, and the commencement of the works, had been accorded. From the year 1853, therefore, the construction of the railway along the extension to Delhi continued in active progress for many years, interrupted only for a short time by the Sepoy mutiny; until the last remaining link of the magnificent trunk line extending over 1000 miles in length, from the new to the old capital of India, viz. the fine bridge over the Jumna at Delhi, was completed in the year 1866.

The East Indian Railway system of lines and branches has now grown to a total length of 1525½ miles. Besides the chord-line with double line of rails, constructed to avoid passing the through traffic by the great loop of the Ganges valley at Rajmahal, and numerous short branches, a long branch of 225 miles, starting from Allahabad, effects a junction with the 'Great Indian Peninsula Railway' at Jubbulpore, and thus links the important Presidency capitals of Bombay and Calcutta in continuous railway communication.

As early as the year 1845 the 'Madras Railway Company' was formed in London, with the object of constructing a railway almost due west from Madras, to an important commercial centre at Arcot, but being unable to obtain any pecuniary concession, the company was shortly afterwards dissolved. In the year 1849 the project was again revived, and application was made for a concession on terms similar to that granted to the 'East Indian' and 'Great Indian Peninsula' Railways; the proposal was, however, rejected at that time, and the project was consequently again shelved.

Soon afterwards, however, surveys and projects for various alternative lines of railway in the Madras Presidency were made, and in 1852 a preliminary contract, with guarantee, was entered into with the 'Madras Railway Company.' The first portion of line sanctioned as an 'experiment' was one from Madras to Menil, a distance of 50 miles, a line which it was considered would be common to other railways leading towards Madras from the north-west and west. This length was commenced in the year 1853, but before much progress had been effected, an extension of the line to Beypore, a small port on the

opposite western coast, was sanctioned; the contract with the Company being signed in December 1855. The first section of the Madras-Beypore railway, 64 miles in length, was opened on the 1st July 1856, and from Arconum, a point situated 42 miles from Madras, a trunk railway was afterwards constructed in a north-westerly direction through Cuddapah to Raichore, effecting a junction at that place with the Great Indian Peninsula line coming from Bombay. The complete connection by railway of the Presidency towns of Bombay and Madras, although it had been early recognised as of Imperial importance, was, however, delayed for some years, partly owing to financial exigencies arising from the Mutiny, and partly to prolonged discussions and surveys of the various alternative routes proposed for the connecting line.

CHAPTER VIII

'EAST INDIAN' RAILWAY AND HOOGHLY BRIDGE

Progress of Railways—Peculiarities of construction in India—Relative value of land—Labour facilities—Manual labour—Small number of over and under bridges—Level crossings, and employment of small bridges and culverts for cross traffic—The large use of iron on Indian railways—India the country of large girder bridges—Methods of founding piers and abutments—Foundation well-sinking of native origin—Description of well-sinking—Erection of iron girder superstructures—Outline description of works on the East Indian Railway—Flood-openings and bridges on the first section—Monghyr tunnel—Route followed by line—Bridge over the Sone river—Description of works—Interruption by mutineers—Tonse bridge—Jumna bridge at Allahabad—Delhi Jumna bridge—Detailed description of recent bridge over the Hooghly near Calcutta—Sinking the pier caissons—Accident—Erection of superstructure—Completion—General particulars of East Indian railway.

East Indian Railway and Hooghly Bridge.

WE have now traced in outline the history and fortunes of the three earliest trunk lines of railway projected and constructed in India. Inaugurated by the opening of the first 20 miles of the Great Indian Peninsula line in the year 1853, the railway system of the country has since steadily expanded, until 40 years later, in 1893, the total length of railways opened for public traffic has reached little short of 17,000 miles, constructed at a capital expenditure amounting to some 227 millions sterling.

The practical construction of railways in India varies little in general methods from those practised in other countries. The leading principles of ordinary railway construction have been already sketched in previous chapters, it will not, therefore, be now necessary to do more than indicate such minor points of difference in constructive details as may be more or less peculiar to the circumstances of India. First then, owing to the generally level character of the country—especially in the

northern plains of Hindustan—the permanent way of railways is carried for the most part on embankment of moderate height, cuttings being of generally rare occurrence. In the construction of 'earthworks,' which form so large an item in the 'formation' of a railway, it is seldom economical or necessary in India to transport soil from one part of the line to another, such as leading or carrying by mechanical means material from cuttings for the building up of embankments. The relative value of land is so small, and labour facilities so great, that, as a rule, the cheapest manner of throwing up embankments is to employ manual labour in obtaining the necessary material from side-cuttings excavated along the sides of the railway, and in the few cases where cuttings occur to place most of the excavated material to 'spoil.' The side-cuttings are shallow detached pits dug parallel with the course of the line, outside the boundary of the permanent land occupied by it. In the more hilly portions of the country through which a railway may be carried, and where more numerous cuttings will necessarily occur, the method of forming the earthworks will still be dependent on economy as governed by the values of land and labour. For the most part, therefore, in India the formation earthworks of a line of railway are carried out by direct manual methods without, as a rule, the intervention of such aids as 'tip' wagons and other mechanical appliances, all the earth or material being brought or removed by large bodies of men, women, and children, in small baskets carried on their heads. This manner of working, however primitive in appearance, is in practice found to be speedy and efficient, as well as economical, wherever a large quantity of labour can be engaged, as is commonly the case.

The generally level character of the country—combined with the comparative rarity of ordinary cross-country roads, and the relatively small number of trains run, prevents also in India the necessity for those numerous over and under bridges intersecting a line of railway so common on European lines. Such bridges—except in the immediate neighbourhood of large towns—are accordingly of rare occurrence, and cross-country roads or tracks are for the most part passed over the lines of rail by means of crossings on the level, gates and a hut or lodge for the

gatekeeper being provided at all vehicle crossings. The railways, as we have seen, are largely carried on embankment, and the numerous drainage under bridges crossing the smaller watercourses, being usually dry for a considerable portion of the year, can be and are, largely utilised as cross-passages for foot-passengers, cattle, and even for the ordinary vehicular traffic of the country districts.

The use of iron in the construction of railways is probably more largely resorted to in India than in many countries. 'Sleepers' of cast-iron, wrought-iron, or steel are greatly used as a substitute for wood, owing to climatic conditions rendering the softer kinds of wood sleepers liable to rapid decay, and to the difficulty of procuring seasoned hard-wood sleepers in sufficient quantity. Although the advantage and economy of masonry structures is fully recognised, iron and steel is also used to a very large extent for the superstructure of railway bridges, not only in those cases where the unavoidable size of opening renders its use imperative, but to a considerable degree in cases where in other countries stone or brick archwork would be preferred. In many parts of India either stone cannot be economically procured, or good brick-earth is difficult to obtain, or it may otherwise be that the conditions of sub-soil for foundation purposes are not suitable for arched structures. Iron or steel bridges of large average size are imposed by the magnitude and conditions of the numerous great rivers of the country, and India is consequently, in a pre-eminent degree, the land of heavy iron bridgework for railway purposes. The foundations of many of these large iron structures present some peculiarities which may be here noted.

The most usual method of founding the abutments and piers of large bridges in the sandy beds—extending often to unknown depths—of the great rivers of the Indian plains is by sinking cylinders, or wells, of brickwork, either singly or in groups, on which the pier superstructures are built; or by sinking the whole pier of an elliptical or other form by means of well-openings or chambers provided in the mass of the masonry. This system is one which is an improved and highly-developed adaptation of old native methods practised in India for centuries in the past. Nearly all the ancient bridges of

Upper India, and even in the more remote regions beyond its boundary, were founded on brick cylinders sunk into the sandy beds of the rivers. English engineers, recognising its suitability, have reduced the practice of foundation well-sinking to a highly-developed art, and have introduced numerous mechanical contrivances and expedients for rapidly sinking the cylinders to great depths, but the *principle* is one entirely derived from native sources. In these wells the brickwork is commenced on timber, or more usually on wrought-iron, curbs of great strength, suspended by vertical tie-rods, passing through iron rings inserted at intervals in the masonry. In the case of circular wells the internal diameter is generally about half the external diameter, so that the thickness of the brickwork will be a quarter of the whole width. The sand or other material met with in sinking is gradually withdrawn through the central hollow of the well by means of suitable mechanical dredgers of various kinds, assisted on occasion by divers working under the water; and after the sinking has been carried to a certain depth—usually about one to two diameters—the wells are loaded with a heavy weight, such as iron rails or bricks stacked upon them, in order to overcome the side friction of the cylinders. These foundation-wells are frequently forced down to great depths, such as 80 to 100 feet, and reaching even 140 feet. When the sinking to the desired depth is complete, the interior space (or spaces) is sealed at the bottom with a certain thickness of cement concrete deposited in the water; the latter is then removed, and the remaining hollow portion is plugged with ordinary concrete or brickwork. Undue scour at the site of the piers is checked by the deposition of large masses of rough stone of great size and weight thrown round them. As the rivers, especially in Upper India, contain little water in the dry season, it is at this period that most of the well-sinking is carried on, and the protective stone is deposited; the latter work being often continued for several seasons, or for such time as may be necessary to replace the rough stone which gradually sinks below the bed during the seasons of flood. During the dry months of the year bridge foundation-wells can largely be pitched directly in position on the exposed surface of the river-bed, but where the operation has to be executed in water of

more or less considerable depth, the foundation blocks are commenced in iron caissons, of varying height to suit the depth of the water, and numerous variations may occur in the special means employed for forcing the wells through the sand or soil of the bed below.

The particular methods adopted for erecting the iron girder superstructures of large bridges have little or no distinctive features in India; these methods, there as elsewhere, are dependent on numerous special or local conditions. Where the height of the work and circumstances of the river admit, the most usual arrangement is to construct between the piers a timber staging of sufficient strength to carry temporarily the weight of the ironwork until it is erected in place piece by piece. In cases where the erection of staging in the river-bed is inadmissible, various other expedients have to be adopted, some of which will be detailed in the examples of particular bridges which follow.

With the exception of a remarkable bridge erected in recent years over the Hooghly channel of the Ganges, the East Indian Railway from Calcutta to Delhi contains no example of engineering construction of the first order of magnitude, but probably few lines can exhibit a greater aggregate number of difficult undertakings, such as in any other country but India would be considered works of a large and important character. The first division of the railway from Howrah to Burdwan, and northwards to Rajmahal and the Ganges valley, traverses a low portion of deltaic land, subject to extreme inundation from the water-system of the country, where the drainage problems to be encountered and solved by the engineers of the railway were of exceptional and extraordinary magnitude. Over this wide expanse of level country, subject to an excessive tropical rainfall, inundations from the flood-spill of the enormous channel of the Ganges and other great rivers, are often spread as a vast sheet over miles of country, converting the whole district into the semblance of an inland sea, from which only the inhabited villages along the higher marginal levels emerge. The formation of long lines of railway embankment, checking the free movement of this expanse of waters, necessitated the provision of an extraordinary number of flood-openings, built

in a peculiarly treacherous soil—having a total area of waterway sufficient to allow the free passage, concentrated at certain definite lower levels, of huge volumes of flood-water, which formerly wandered unrestricted over many miles of country. In addition to these numerous flood-openings, entirely confined to the disposal of the inundations from the main rivers, the course of the East Indian Railway along the low-lying portions of the Ganges valley necessitated the crossing at their widest points of an unusually large number of important channels and broad deep rivers, requiring bridges or viaducts of heavy dimensions: such were the viaducts over the rivers Adjai and Mor, the first spanned by 32 brick arches, each of 50 feet, and the second by 24 arches of the same size; the Dwarka and Brahmini bridges of 7 and 9 girder spans of 60 feet; the latter having 7 masonry arches of 24 feet in prolongation, and the Pugla bridge of 25 spans of 28 feet, and 4 of 60 feet girders, together with a succession of others of scarcely inferior opening. The total length and area of waterway in viaducts, bridges, culverts, and flood-openings along this portion of the East Indian Railway is probably greater than on any equal length of line in existence. The foundations of these structures, and generally of all similar constructions on this side of India, were formed by sinking blocks of masonry perforated with holes or wells, through which the soft alluvial soil and sand below the blocks was withdrawn by means of dredging instruments, the sinking being continued until a bed of clay was met with; or failing this, until a depth was reached considered sufficient to place the foundation beyond the reach of scour.

After passing the bend of the Ganges at Rajmahal the railway is carried on the higher marginal land between the river and the inundated districts situated on a lower level than the river-bed, crossing all the numerous intersecting channels, and requiring much heavy earthworks and bridge and flood-arch construction; the larger bridges here consisting of from 3 to 7 openings of 60 feet girders. Near Monghyr occurs the only example of a tunnel on the East Indian Railway. This tunnel, through the last spurs of the Kymore hills, is of short length; being only 900 feet long, pierced through 600 feet of clay slate, about 500 feet of which required brick-lining, and 300 feet of

quartz rock of exceptional hardness. A short distance beyond Monghyr the line encounters severe obstacles. Here a large portion of the accumulated flood-spill of the Ganges passes through a gap in the marginal bank of the river, and during the season of floods the whole country is often under water to a depth of 8 or 10 feet. Through the opening two rivers of considerable magnitude also pass, viz., the Keeul and the Hulohar. In order to carry the line onwards, no less than 630 flood arches, each 15 feet span, were required. The Keeul river was spanned by 9 girder openings of 150 feet, and the Hulohar by 4 spans of similar size, the piers and abutments being founded on brick-wells of 10 feet and 20 feet diameter, sunk from 25 to 45 feet into the river-bed. Altogether—including flood-openings—to pass this gap no less than 11,400 lineal feet, or over two miles, of waterway was provided. The original Bengal section of the East Indian Railway, from Burdwan *viâ* Rajmahal to the border of the Bengal province at the Kurumassa river, is 416½ miles long. The construction of this difficult length involved not far short of 1000 millions of cubic feet, or 37 million cubic yards, of earthworks, and nearly 40 millions of cubic feet, or a million and a half of cubic yards, of brickwork, of which latter 8½ millions of cubic feet were situated in one short length of 21 miles.

The above examples, out of a large number that might have been quoted, will serve as an illustration of the extraordinary character and nature of the drainage difficulties encountered by the East Indian Railway along the lower portion of the Ganges valley. It was hardly to be expected that, nearly forty years ago, railway engineers, fresh from England, and working under an entirely novel set of conditions, should at once have fully grasped the exceptional nature of the problems presented, in providing for the efficient drainage of a line of railway in such a district as Bengal. The experience of the first few years corrected numerous initial mistakes, and supplemented insufficient precautions. In many cases bridges as at first designed proved far too small, and had to be extensively enlarged, a quantity of additional flood-openings had to be provided, and foundations injured or undermined by the force and volume of the pent-up floods had to be strengthened and secured. The

lines in India. The Sone river, rising in the elevated districts of Central India, traverses the plains of South Behar, and discharges itself into the Ganges, near Patna, after draining an area of nearly 23,000 square miles. Its extreme discharge in floods is said to be about $1\frac{3}{4}$ million of cubic feet per second. The chief peculiarity of the river is the great width of its channel in the lower reaches. For the greater part of 100 miles it is over 2 miles wide, and reaches as much as 3 miles. This wide expanse of bed, through which during eight or nine months of the year only a narrow stream meanders, consists entirely of fine sand, appearing to the traveller like the surface of a great sandy desert. During the season of floods, the depth of water carried averages barely 20 feet, and it seldom exceeds 30 feet in the deepest parts. The whole width of the immense channel is, moreover, rarely completely covered. After careful examination of this formidable obstacle to the railway, a narrow point not far removed from the natural direction of the line was selected. Here the river was only about 4000 feet in width; and the banks were high and composed of clay, a bed of clay was also found by borings to underlie the sand across the whole width of the bed. It was at first proposed to construct a bridge of brick arches; but after some discussion, it was finally decided to adopt brick foundation-wells, with piers of similar material, used to support a superstructure of wrought-iron girders, each of 150 feet span, carrying the rails on the top, and having an ordinary roadway below. The foundation of the first pier sunk in the year 1856 was composed of a group of twelve brick wells, each 10 feet in diameter, laid close together in two rows of five, with additional wells at either end for the cutwaters. Initial work on the bridge was well in hand, when in July 1857 the native regiments at Dinapore mutinied, and marching towards the west, overran the works. 'The resident engineers, their wives and children, together with inspectors and overseers and their families, escaped in the iron boats belonging to the railway company to Dinapore, and the mutineers left nothing untouched that was destructable; then continuing their march along the line they came to Arrah, where Mr. Boyle, the resident engineer, had fortified a house. To it the European

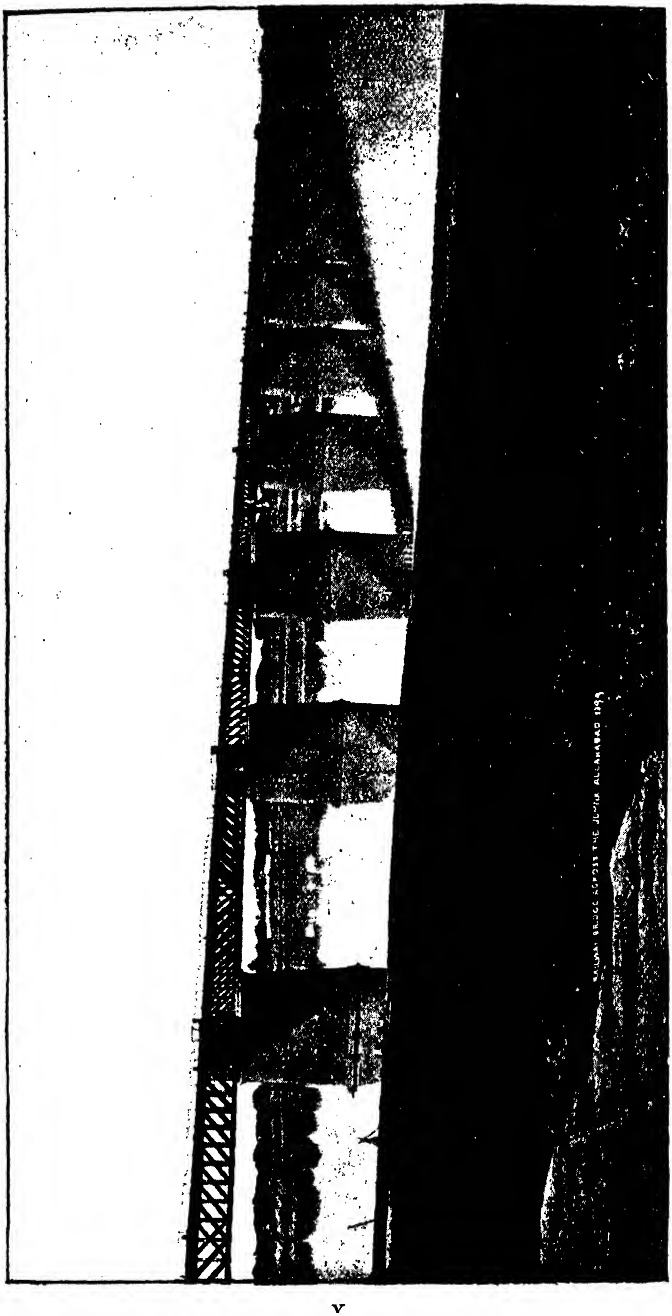
residents, 16 in number, with 45 Sikhs, retreated, and bravely defended themselves for a week against immense odds. The mutineers after crossing the Sone had been joined by a chief called "Koor Singh," and numbering about 2500, had invested the house occupied by the residents of the civil station of Arrah, against which they fired a field-gun which was in their possession. The little garrison, however, bravely held the place until relieved by a force under Major Eyre, Bengal Artillery, who, marching from Buxar, defeated the rebels in an action near the town of Arrah.'

It has been estimated that the value of property destroyed in 1857-58 by the mutineers at the Sone bridge alone was £42,000; and that the total loss from the mutiny, on all heads of account suffered by the East Indian Railway Company, over the whole line, amounted to an equivalent of three millions sterling.

Work at the bridge site was of course suspended, and could not be resumed until November 1858, when operations had practically to be commenced *de novo*. The design for the pier foundations was now modified, and in place of the cluster of small 10-feet wells originally intended, the piers were founded on three wells, each 18 feet in diameter, built on very strong wrought-iron curbs, having vertical iron rods attached to them connected with horizontal rings of iron built at intervals into the brickwork. The foundation-wells were sunk into the river-bed to an average depth of 32 feet below low-water, entering into a bed of stiff clay, and by the year 1860 construction work on all the piers was in full progress. As soon as the piers were completed, the girders were rapidly erected by the aid of a timber staging; and the bridge was virtually finished by the end of the year 1861, its final completion being unfortunately delayed by the loss of certain portions of the iron work in transit, so that it was not ready for traffic until the end of 1862. The section of main line as far as Moghul Serai, was soon afterwards officially opened by Lord Elgin, Viceroy and Governor-General, viz. in February 1863. The initial cost of constructing the Sone Bridge, which was completed for a double line of rails—including protective works—is given as 33 lakhs of rupees or £330,000 at par.

The bridge over the Tonse river, situated in the Mirzapore district, about 21 miles east of Allahabad, was completed in the year 1864, and enabled the line to be opened as far as that city on the 1st April of the same year. The bridge has seven spans of latticed iron girders of 150 feet clear opening, and the piers and abutments are constructed of brickwork, the cutwaters, being faced with dressed stone, they are carried on groups of brick wells, each 12 feet in diameter, sunk into clay at about 15 feet below the river-bed. The girders are deck-spans, similar to those of the Sone, carrying an ordinary roadway below. The advantage of utilising the larger railway bridges for the double purpose of carrying an ordinary cart or foot-road, as well as the railway, has been everywhere fully recognised in India, and a small toll levied on the traffic, probably in the majority of cases, amply repays the slight extra cost of the provision.

At Allahabad, the East Indian Railway crosses the Jumna river just before its junction with the Ganges, by a handsome bridge of larger openings, and of much greater height than that over the Sone, but of somewhat shorter total length. The site for the bridge was fixed so early as the year 1855; but owing to various causes, the design was not finally decided upon until after the Mutiny, and actual work on it was not commenced until the summer of 1859. The first design was for a bridge of 15 openings, each 200 feet long; but on a further investigation of the maximum flood discharge of the river, one span was suppressed. The bridge, therefore, as constructed, consists of 14 deck spans—carrying a cart-road below —of 200 feet each, and three small openings of 30 feet. The piers, which are 60 feet high above low-water, are founded on groups of twelve brick wells, each 13½ feet in diameter, sunk to an average depth below low-water of 42 feet. The average height, therefore, of the pier masonry, from the well curbs to the under side of the girders, is 102 feet. The total length of the bridge, from end to end, is 3235 feet. The girders, which are of wrought iron, and constructed for a single line only, are of the open lattice tubular form. During the sinking of the wells, the up-stream end of No. 11 pier was undermined by a flood and overthrown; the overthrown portion was, however,



JUMNA BRIDGE, ALLAHABAD

by the aid of a cofferdam, reconnected with the body of the pier, and the whole was protected against scour by a large mass of rough stone. The total quantity of masonry and brickwork in piers and abutments is given as 2½ millions of cubic feet (or 92,600 cubic yards); whilst at a short distance, on the northern approach, occurs a viaduct of 24 arches of 30 feet each. The initial cost of this, the finest of the many railway bridges over the Jumna river, was 44½ lakhs of rupees, or £445,000, and it was opened for public traffic in August 1865, permitting from that date uninterrupted communication between Calcutta and Agra.

The important cities of Agra and Delhi are both situated on the right bank of the Jumna, whilst the course of the railway beyond Allahabad is on the left bank. Agra is approached by a branch from a junction at Tundla; and the main line proceeds northwards to Ghazibad, from which place it turns sharply to the west, and again crosses the Jumna before entering the ancient city of Delhi by a bridge which is the last of the large structures on the East Indian Railway. The Delhi Jumna Bridge consists of twelve deck spans—with cart-roadway below—of 211½ feet each. The piers, which are 23½ feet high above low-water in the river, are carried on ten brick wells, each 12 feet in diameter, disposed in two rows of four each, with single up and down-stream wells for the cut-waters. Both abutments and two of the piers on the Delhi side of the river are, however, founded on rock, which occurs at a few feet below the surface. In the case of the other piers, the wells are carried for an average depth of 39 feet into the river-bed into stiff clay. The total length of the bridge, which has been constructed for a single line, is 2640 feet; and it was constructed at a cost of £166,000. The structure was opened for traffic at the end of 1866, finally completing through communication between Calcutta and Delhi.

It has been mentioned that on the first commencement of the East Indian Railway in the year 1851, it was determined —in order to postpone the construction of a railway bridge over the Hooghly, which could not be otherwise than exceedingly expensive—to establish the terminus or starting-point of the line at Howrah, a suburb situated opposite Calcutta on

JUMNA BRIDGE, DELHI

the right bank of the Hooghly tidal channel; communication between the city and Howrah being in the meantime maintained by means of a steam-ferry.

In the year 1875—to meet the growing necessities of the Calcutta traffic—an ingeniously constructed pontoon bridge, to carry an ordinary carriage-way, supported at an unusual elevation above the level of the pontoons, was constructed across the Hooghly, and this means of communication has since continued in use, to the great convenience of the town. The urgent need, however, of a bridge over the Hooghly capable of sustaining a railway, remained unsatisfied until so recently as the year 1887.

The remarkable railway bridge commenced in the year 1883-4, and opened in the year 1887, has been constructed over the Hooghly tidal channel at a point of the river situated 28 miles above the pontoon bridge, which connects Calcutta with the Howrah terminus, and by its means a junction is now effected between the East Indian main line and the Eastern Bengal Railway, leading into the heart of Calcutta. The bridge crosses the river at the town of 'Hooghly,' a place which, a couple of hundred years ago, was the principal port and factory of the British Company of Merchants in Bengal, and from which the whole channel has taken its name. As a consequence of the year in which the bridge was opened, viz., the 50th year of the reign of her Majesty, Queen Victoria, Empress of India, the structure itself has been appropriately named the 'Jubilee Bridge.'

The particulars embodied in the following outline-description of this fine engineering work, are chiefly derived from a paper on its erection read before the Institution of Civil Engineers on the 24th January 1888, by Sir Bradford Leslie, K.C.I.E., M.I.C.E. At the site of the 'Jubilee' Bridge the Hooghly channel is 1200 feet wide at low water, the selection of the precise point of crossing having, among other considerations, been largely influenced by the relative narrowness of the river immediately opposite the town of Hooghly. On the town- or right side of the river, the bed is 66 feet deep below mean sea-level, and the bank is defined and well above the highest floods. On the left side the water is comparatively

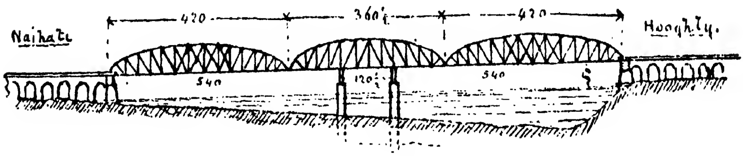
JUBILEE BRIDGE OVER THE HOOGHLY NEAR CALCUTTA

shallow, and there is a low bank, with a wide stretch of low-lying ground beyond, inundated during high floods. The height of the tide varies from a short distance below mean sea-level to 20 feet above, with a maximum velocity of 4½ miles an hour when the flood-tide enters with a strong bore, and nearly 6 miles an hour on the ebb-tide in freshets. There is a very large navigation, consisting of unwieldy country sailing-boats, little under control, and steamers and flats of 500 to 600 tons burden belonging to the Inland Navigation Companies, together with the passenger steamers plying between Calcutta and Kulna.

The bridge is constructed for a double line of railway, both lines being carried between the main girders. It consists essentially of two large openings, each of 524 feet clear span, with a central smaller opening of 106½ feet, between two piers supporting a pair of central cantilever girders; the total length of the bridge proper being 1213¼ feet. The approach to the main structure on the Hooghly side of the river is by a masonry viaduct 3278 feet in total length, consisting of 112 brick arches of spans varying from 10¾ to 48 feet. On the Naihati, or left side of the river, the approach is also by a masonry viaduct, in this case 441 feet long, consisting of 29 arched openings of 10¾ feet. From end to end of the viaducts, therefore, and across the river, the total length of structure is 4932 feet, or not far short of a mile. The height of the main bridge from the bottom of the foundations of the central piers to the under side of the girders is 153½ feet, the foundations being 98½ feet below the lowest water.

The superstructure of the bridge consists of three sections of steel girders, each of the open triangular type, having straight bottom members on which the railway is carried, and curved in bow-form above. The total weight of steel in the bridge superstructure, including the standards on the piers, is given as 3876 tons, and the three sections into which the superstructure is divided are respectively 420 feet, 360½ feet, and again 420 feet in length. The central-girder section of 360½ feet is carried on two piers placed only 120½ feet apart from centre to centre, the girders of this section have consequently an overhang or projection of 120 feet on either side of the supporting piers.

Resting on the overhanging or projecting ends of the central cantilever girders, the two land-girders, each 420 feet long, stretch to the bank abutments. The object of this somewhat unusual arrangement, giving two very wide land-spans, and a smaller one in the centre (lying between the two piers supporting the central cantilevers) was partly in order to locate the piers in comparatively shallow water. If a bridge of three equal openings, say of 400 feet, had been adopted, the pier on the Hooghly side of the river would have fallen in 40 feet of water at low tides, and the cost of foundation construction would have been greatly enhanced. There were, moreover, other advantages in the design. The position chosen for the two piers leaves the widest openings on each land-side of them for navigation, that on the shallower side, where the current is more moderate, for the native craft, and that on the deep side



SKETCH DIAGRAM OF HOOGHLY BRIDGE.

of the channel for the use of steam vessels and flats. The founding of the two piers and the erection of the superstructure steel-work of the girders by the particular methods employed, which were virtually imposed by the conditions of the river, as well as by considerations of labour and rapid execution, was also at the same time facilitated by the design. The general form of the bridge will be best understood from the sketch-diagram above, from which also it will be seen that the structure is far from being graceful in outline.

The two piers are each 66 feet long, up and down stream, and 25 feet wide, with semicircular ends and flat sides, and the average depth of the water at the place where they are pitched is about 27 to 30 feet at low spring-tides in the dry season. The main body of each pier is enclosed by a wrought-iron caisson, 108 feet high by 66 feet long, and 25 feet in width, weighing 453 tons. Each caisson was divided into three exca-

vating chambers (open from top to bottom), by two buoyancy chambers extending its full width, and 15 feet wide. The lower portions of the caissons, which were provided with tapered curbs or cutting edges, were floated into position and sunk through the water and soft silt of the river bed by the aid of a pair of floating pontoons moored between them, the pontoons being furnished with suitable stagings and powerful tackle, commanding the site of both piers simultaneously. As the sinking progressed, additional sections were built on the top of the caissons, until at length the bed of stiff clay selected for the foundation was reached, and into this clay the lower edge was forced, some 10 or 12 feet, to a depth of 98½ feet below the lowest water in the river. The whole interior of the caissons was filled in solid with concrete and brick-work, brought up to the necessary level to carry the steel standards on which the cantilever girders rest.

The many difficult operations connected with the sinking of these pier-caissons were successfully carried out, but not entirely without mishap. On the 16th April 1884, the lower portion of one of them, drawing 32 feet of water, and weighing with load some 750 tons, had been floated ready for placing in position, when it was caught by a strong bore in the river. The chain lashings by which the top had been secured to the pontoons, and the chain tackle of the up- and down-stream moorings, were broken by the violent strains to which they were subjected, and the caisson being released, was carried away by the current, and floated nearly half a mile up the river, where it grounded. By the aid of extraordinary exertions it was, however, secured, lightened of 40 tons or so of cement brick-work, and at length refloated by the evening of the following day, being fortunately found to have sustained no serious injury, so that before very long it was again ready for deposition on its permanent site.

The foundations of the two abutments of the bridge presented no unusual difficulties, and were sunk on two iron curbs 65 feet long, 28 feet wide, and 8 feet deep, divided into three excavating chambers. On the Hooghly side the curb was sunk about 40 feet, and on the Naihati side about 84 feet below the river bank. The steel standards placed on the piers for carry-

ing the cantilever girders are vertical cellular structures 20 feet high, built up of plate and angle bars riveted together, and secured to the brick-work of the piers by holding-down bolts and anchor-castings. The standards each contain 205 tons of steel.

The central portion of the cantilever girders, or that portion lying between the piers, was erected by means of a platform supported by raking struts from the pier-sides, and the overhanging portions were then built out, piece by piece, by the aid of overhead tackle until completed. The girders for the land-spans were each erected on lines of rails carried on the surface of the two approach-viaducts, which were designed and strengthened in the necessary manner to bear them. A complete span, composed of two connected girders weighing 1000 tons, was then mounted on rollers, and the whole mass was run forward by the aid of steam tackle, until the outer end of the girders projected over the water for some distance beyond the face-line of the abutment; the portion so projected having been previously temporarily strengthened. At this stage of the operation the two floating pontoons which had been employed for sinking the pier caissons, and which were now fitted with a suitable staging, were brought into position beneath, and the projecting ends of the girders were wedged-up and supported on the pontoon staging. The whole was then once more moved forward; the pontoon carrying the outer ends of the girders being now warped across the current, until these ends were brought into position, and deposited on the projecting extremities of the cantilever girders.

These operations, of extraordinary magnitude and difficulty, requiring the most exact calculation, and adaptation of means to ends, were carried out with the utmost precision. The girders on the Hooghly side of the river were launched on the 8th November 1886, and those on the Naihati side on the 20th of the following month, the operation in each case occupying about five hours only. The actual construction of the Jubilee Bridge was commenced in the year 1884, it was practically completed by the end of 1886, and was formally opened for public traffic on the 25th March 1887. The total cost of the bridge, including the two long approach viaducts, is given as

£261,178, or, stated in rupees, after deducting the cost of plant and supervision, the total expenditure incurred on the whole work is officially shown as Rs. 30,95,388.

The length of the main line of the East Indian Railway, including the chord line of 186½ miles, is 1205 miles. In addition, the main line has fifteen branches, aggregating 320½ miles, most of which are short, except that from Allahabad to Jubbulpore, which is 224 miles in length. The total length of main-line and branches amounts, therefore, to 1525½ miles. Of this, the distance from Howrah to Moghal Serai (the junction for Benares) is laid double, which, together with some other short lengths, brings up the total length of double-line to 474 miles. The earthworks and bridges are generally everywhere constructed for a double line, except the bridge superstructures.

The permanent way is laid with rails varying from 74 lbs. to 82 lbs. per yard. Originally the line was laid almost entirely with wooden sleepers, but cast-iron plate sleepers have since been largely introduced, and are now mostly used for renewals. About 1200 miles have also been relaid with steel rails in place of iron. On the Jubbulpore branch wooden sleepers of creasoted pine and sal are the most numerous. The East Indian Railway was acquired by the State from the late Guaranteed Company on the 1st January 1880. The working and management is still, however, carried on by a company under contract with Government.

CHAPTER IX

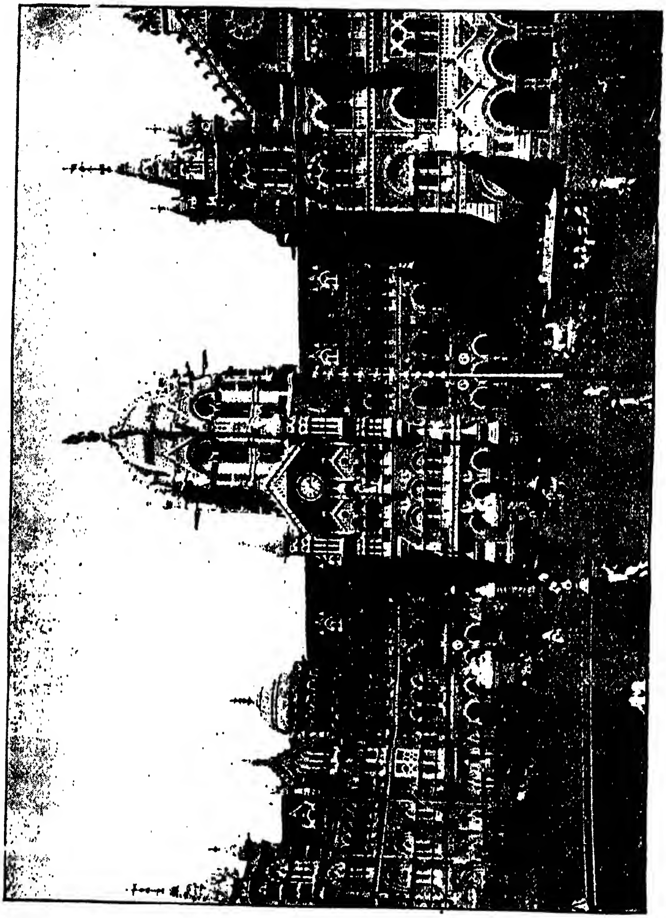
'GREAT INDIAN PENINSULA' AND 'MADRAS' RAILWAYS

The Great Indian Peninsula Railway—Sketch of principal engineering works—Bombay to Callian—The Western *ghâts*—Detailed description of the Thul *ghât* incline—Gradients and curves—Earthworks—Viaducts and reversing station—Tunnels—Route followed by main line and branches—Tapti river viaduct—Nerbudda bridge—The Bhore *ghât* incline—Detailed description—Difficulties of undertaking—Gradients and curves—Works on the Bhore *ghât*—Stations on the incline—Reversing station—General particulars of viaducts and tunnels—Peculiar difficulties—Surprising magnitude of the works—Route of railway from Lanowlee, and principal works—Main particulars of Great Indian Peninsula Railway—The Madras Railway—Routes and outline of principal bridges—General particulars—Concluding observations.

Great Indian Peninsula Railway.

THE early history and general course followed by the lines belonging to the 'Great Indian Peninsula Railway' have been already outlined. It remains, therefore, to sketch some of the principal engineering works on this important trunk system of railways, extending from Bombay to Jubbulpore, with a long branch to Nagpur on the north-east, and to Raichore, where it joins the 'Madras Railway,' on the south-east. The terminus of the Great Indian Peninsula system is situated in a central and convenient position on the island of Bombay, where during recent years has been built, certainly the largest and handsomest terminal station to be met with in India, and, moreover, one which will enter into comparision with any of the large railway stations of the world.

A short distance from the terminus, viz., at Byculla and Parel, are situated the extensive goods depôt and locomotive work-shops of the railway. At Sion, the extreme north-eastern point of Bombay island, a short branch was originally



BOMBAY TERMINAL STATION

constructed to the old town of Mahim, situated at the western extremity of the island, once the principal seat of the commerce of Bombay, though now of relatively small importance. The railway crosses the wide Sion marsh to the island of Salsette by a long embankment, and near Tannah, at 22 miles from the terminus, it crosses the arm of the sea which divides Salsette from the mainland of the Concan and of India by two arched masonry viaducts, 333 and 579 feet long respectively, in the latter of which is an iron girder opening for passing the navigation. Traversing a portion of the Concan, the line reaches the junction station of Callian at 33 miles from Bombay. This point marks the end of the original 'experimental' line, opened on the 1st May 1854 (the first 20 miles to Tannah having been opened about a year earlier), and is the point from which the two trunk lines to Jubbulpore and Raichore bifurcate, each climbing by separate passes, situated respectively to the north-east and south-east, the rugged line of the Western *ghâts*, in order to gain the upper table land of the Deccan.

It has already been pointed out that the line of the Western *ghâts*, as approached from Bombay, is not to be regarded as a chain of mountains or hills, but as a precipitous line of cliffs, some 2000 to 3000 feet high, forming the vertical wall of the Deccan high land; this line of precipices being only broken by deep ravines, or rifts along its face, with occasionally projecting spurs running down to the Concan. The first section of the railway from Callian to the north-east, and in the direction of the Thul *ghât*, is one of 26 miles, extending from Callian to Kasora. On this length the line gradually climbs by steep gradients of principally 1 in 100, and by sharp curves down to a radius of 30 chains, the south side of a long irregular spur which descends westwards from the main *ghât* precipices, and separates the ravines or valleys of the Basta on the south from the Wyturnee on the north. The works on this section are of a heavy character. The earthwork formation contains over half a million of cubic yards of cutting through hard trap and basaltic rocks, and over 1⅓ million cubic yards of embankment. Rifts, or ravines, are crossed by four important viaducts of which the two longest are 372 and 429 feet long, and no less than 127 and 122 feet high. There are also forty-four bridges

up to 30 feet span, and 117 minor culverts. The level of Kasora, placed 1040 feet above the sea, is 849 feet higher than Callian, and as the level of the summit of the Thul *ghât* incline is 2012 feet above sea-level the height now gained by the railway leaves 972 feet still to be surmounted before the upper tableland is reached.

The actual Thul *ghât* incline is considered to commence at the Rotunda *nulla*, or stream, at Kasora, and extends from thence to Egutpura, on the summit of the pass. The preliminary surveys and studies for this remarkable example of railway engineering occupied 4 years, and its actual construction was commenced in October 1857. The total length of the incline, which has been constructed for a double line throughout, is 9½ miles, having a rise of 972 feet in this short distance, or an average ascent of 102·21 feet per mile, or about 1 foot rise in every 53 feet of length. The actual gradients, however, vary, the steepest being an incline of 1 in 37 for a length of 4 miles 30 chains—that is, for about one-half of the whole ascent. Other gradients are 1 in 45 for 838 feet, and 1 in 50 to 1 in 148, and in the total length there is only 3036 feet of level line.

Of the 9½ miles comprising the *ghât* section from Kasora to Egutpura, close upon 6 miles are curved, the remaining 3½ miles being straight. The radius of the curves varies from the sharpest, which is 17 chains (1122 feet) up to 100 chains. The sharpest curve has a length of 2178 feet, another of 20 chains radius has a length of 3000 feet. The total length of curves of 20 to 50 chains radius is over 4½ miles, those from 50 to 100 aggregating 3168 feet only.

The quantity of earthworks, consisting for the most part of hard rocky materials, on this short length of line, is no less than 67 millions of cubic feet, or 2,486,000 cubic yards, the quantity in cuttings and in embankments respectively being about equal. At the commencement of the Thul *ghât* incline the Rotunda *nulla* and ravine is crossed by a viaduct 90 feet high, and 198 feet long. Passing through a rock tunnel of about 400 feet, the railway reaches the Manda Sheyt ravines, which are crossed by two lofty viaducts, the first 84 feet high, and 429 feet long, the second 87 feet in height and 198 feet

long, adjoining which are two tunnels 240 and 1625 feet long respectively. At $3\frac{1}{2}$ miles from Kasora the line reaches a short level length, or station, situated for the most part on high embankment, where the direction of the railway is suddenly altered, the engines being here turned and transferred by means of a turn-table and sidings, from one end of the trains to the other. Hitherto the line has ascended the south, or river Basta side of the great projecting spur. After leaving the reversing station, however, it passes through a gap in the ridge and gains the northern, or Wyturnee valley side. Passing through three tunnels, the longest of which is 705 feet in length, and over a viaduct 90 feet in height and 198 feet long, the railway encounters in the sixth mile some of the most formidable difficulties on the *ghât*. Over the Ehegaum ravine is thrown a magnificent viaduct, 750 feet long, and of the great height of 182 feet, whilst the sides of the hill are pierced by four tunnels, the two longest of which are 1461 and 1247 feet respectively. The railway now creeps painfully up the steep side of the cliffs, and, before reaching the summit-level at Egutpura, traverses three other tunnels of 783, 420, and 174 feet, and passes over another viaduct 450 feet long and 60 feet in height.

The tunnels on the *ghât* incline are for the most part pierced through greenstone or basalt rock of the hardest description. With the exception of the Ehegaum ravine viaduct, the superstructure of which consists of three spans of triangulated iron girders placed 182 feet above the stream below, and having semicircular arches of 40 feet at either end—all the viaducts and smaller bridges are arched structures, built chiefly of basalt masonry. Altogether on the $9\frac{1}{2}$ miles of the Thul *ghât* ascent there are thirteen tunnels, having an aggregate length of 7956 feet, six lofty viaducts, having a total length of 2223 feet, and ranging from 82 to 182 feet high, fifteen bridges of spans varying from 7 to 30 feet, and between sixty and seventy culverts.

Leaving Egutpura, on the summit of the *ghât*, the line, encountering only ordinary obstacles, crosses the fertile valley of the Upper Godavery, and passing by an easy gap the Indyhadree range of hills at Munmar, enters the rich districts of Candeish; traversing which, the railway reaches the junction and locomotive station of Bhasavul, 276 miles from Bombay.

The works along this section, although numerous, are of secondary character. At Bhasavul, a long branch of 245 miles extends to Nagpur, the capital city of the Central Provinces, traversing and connecting with Bombay one of the best cotton-producing districts in India. The country is generally favourable, and no individual works require detailed mention. The principal viaducts are those over the rivers Mund and Wardha, the former consisting of fifteen openings of 60 feet, with piers 70 feet high, and the latter of twelve openings of 60 feet each.

Soon after leaving the junction station of Bhasavul, the main line sharply curves to the northwards, and crosses the important Tapti river by a handsome viaduct, carried at a height of 60 feet above low water. This viaduct, which is 2556 feet long and constructed for a double line, consists of twenty-eight openings of 60 feet, and five larger spans of 138 feet each. The piers are formed of a pair of iron cylinders filled with concrete, resting on the solid rock, which forms the bed of the river, and nowhere located at a greater depth than 16 feet below the lowest water. The cost of the structure is given as £163,000. The present Tapti viaduct is a reconstruction, the original one erected with masonry piers having failed, partly from faulty construction, and partly from the sudden and violent floods—rising sometimes to a height of nearly 70 feet above the lowest bed—to which the river is liable.

The section of line from Bhasavul to Jubbulpore, 339 miles in length, passes, a short distance beyond the Tapti, through a gap in the Satpura range of hills, with gradients nowhere steeper than 1 in 100, and enters the valley of the Nerbudda, continuing along the left bank of that river for about 200 miles. The country is for the most part flat, and favourable for railway construction, but the line necessarily encounters a large amount of cross drainage falling into the main river, requiring a series of heavy and expensive bridges and viaducts, although none of these are of exceptional individual size. Before reaching Jubbulpore, 615 miles from Bombay, and effecting a junction with the East Indian branch line from Allahabad, the railway throws off a short branch of 12 miles to the coal fields of Mohpani, and crosses the upper part of the Nerbudda river itself by a viaduct and bridge 1052 feet long, consisting of six arched

openings of 40 feet, and five girder spans of 137 feet, placed 81 feet above the lowest water. The foundations of this structure presented no difficulty, beds of solid rock being found almost on the surface. The piers and abutments of the Nerbudda bridge are built for a double line, the girder superstructure for a single line only. The total cost of the work is given approximately as £67,000.

Returning now to Callian, below the Western *ghâts*, the point from which the two main trunk lines of the Great Indian Peninsula Railway bifurcate—one going north-east to Jubbulpore, the other south-east to Poona and Raichore—the first section of the south-east extension passes by a fairly easy line of 30 miles to the foot of the Bhore *ghât* incline. This short length is, however, exposed to extraordinary floods from the rapid and violent torrents which descend from the line of *ghâts* and hills on either side, and is consequently provided with an unusual number of the smaller class of bridges and culverts. The works necessary for carrying the line of railway up the Bhore *ghât* are of extraordinary magnitude and difficulty. Before the route could be pronounced economically passable for a railway, many years had to be expended in preliminary studies and surveys, until at length a series of inclines was laid out, on one portion of which it would still be necessary for trains to be dragged up by means of a stationary engine; but as time went on, closer and more detailed examination gradually enabled the engineers to modify bit by bit, and improve little by little the possible alignment, until at last a route was planned out which, although involving a succession of stupendous and costly works, was nevertheless pronounced to be passable by locomotives along its whole extent, and the work of actual construction on this bold and difficult undertaking was commenced in January of the year 1856.

The Bhore *ghât*[1] incline commences near the village of Padushurree or Kurjut, about 30 miles from Callian, and

[1] The data for this description of the Bhore *ghât* incline, as well as that of the previous description of the incline on the Thul *ghât*, is principally derived from a paper read before the Institution of Civil Engineers, by J. J. Berkeley, Esq., M.I.C.E., on the line and works of the Great Indian Peninsula Railway, in the year 1859-60.

ascends from thence to the highest summit level of the *ghât*, situated at Lanowlee, 2027 feet above the sea. The total length of the incline is 15 miles 68 chains, and the total rise in this distance, from the level ground at the foot of the *ghât* to the summit level, is 1831 feet, the average rise over the whole distance being 1 in 46 feet of length. The actual gradients on the ascent, however, vary according to the necessities of the ground, and in consequence of the obligation on so great a length of rise of introducing short breathing places of level line. The whole incline is, in fact, divided into four sections, separated from each other by short lengths of level and contrary rise, to enable the speed of the *descending* trains to be checked, and the trains themselves to be brought to a stand. The steepest gradients on the ascent are 1 in 37, extending in one length for 1 mile 38 chains, and 1 in 40 for 8 miles 4 chains, the remaining grades being 1 in 42 and 1 in 75, with a short length of 1 in 330 at Khandalla station. The total extent of level line amounts to 1 mile and 15 chains only.

Out of the whole 15 miles 68 chains of incline forming the total ascent of the Bhore *ghât*, no less than 10 miles 34 chains are curved. The sharpest curve is one of 15 chains, or 990 feet radius, on a gradient of 1 in 75, having a length of 1452 feet, Another, 660 feet long, has a radius of 20 chains, and the remaining curves, of various lengths, are from 30 to 80 chains radius; the total length of the straight portion being 5 miles 34 chains. A double line of rails of the 5 foot 6 inches gauge is carried throughout the entire ascent of the *ghât*, making one of the widest and most splendid mountain roads in the world. It is not easy by means of mere quantitative figures to convey an adequate idea of the magnitude of engineering achievements; so large a portion of the real difficulties encountered depending far more on the special features and conditions of the obstacles that have been overcome, than on the mere quantity of materials removed or built up. The double line of railway of broad gauge constructed up the Bhore *ghât* consists of a continuous series of heavy cuttings and embankments, reaching 76 feet in depth or height on the central line, broken up by a rapid succession of tunnels pierced through projecting head-

lands, and by bold lofty viaducts of masonry over the deep rocky ravines and gorges with which the face of the precipitous cliffs is constantly intersected. The cuttings and tunnels are, for the most part, blasted through basaltic rocks of the hardest description, and embankments are largely built up of rocky materials. The line is frequently carried clinging to the steep hill-sides, with the inner portion of its formation surface notched or benched into the rock, whilst the outer portion is carried on artificial bank, having an enormous outward slope, or the outer half may be supported by long lengths of masonry retaining-wall built up from great depths below, or be carried on a series of arch-vaulting planted against the slope. In many such situations, as well as elsewhere, the line is exposed to the frequent danger of landslips from the steep slopes situated above its course. The soil, filled with massive boulders of rock, becoming loosened by the heavy tropical rains, huge masses are liable to be dislodged and projected downwards with terrific violence, and, unless prevented, may dash into and create havoc on the surface of the railway. In some of these places the amount of labour and expense involved in reducing or protecting the upper slopes; in the construction of catch-water drains, and overhead passages for discharging the collected water over the course of the railway into the valley below, in order to obviate the risks of landslips, is enormous.

The total quantity, of mostly hard rock-cutting—reaching a maximum depth on the central line of 76 feet—on the Bhore *ghât* formation of the railway is upwards of 54 millions of cubic feet, or 2 millions of cubic yards. The quantity of material in the embankments aggregates 67½ millions of cubic feet, or 2½ million cubic yards, and owing to the excessive steepness of the sidelong ground along which the banks are carried, whilst the height on the central line may be 50 to 75 feet, the toe of the outer slope is, in some cases, situated in the valley 150 to 300 feet below the formation level.

There are four stations on the incline, the first, named Thakurwada, is placed at a distance of 5 miles from the bottom, and is provided with catch, or safety sidings, into which any descending or runaway train, or detached vehicles,

can be turned and stopped when necessary; the second is a reversing station, situated at Battery Hill, in the 12th mile; the third is at Khandalla, in the 14th mile; and the fourth at Lanowlee, on the summit level of the *ghât*. At the reversing station—by means of a turntable and sidings—the engines are turned and brought round to the other extremity of the trains, which then proceed in a reverse direction to that from which they entered. The principal object of this arrangement was to prolong the length of base, and to reach the highest possible level before attacking the difficult features of the main *ghât* precipice lying between the reversing station and Lanowlee.

At the commencement of the ascent from near Padushurree the railway is carried, nearly in a semicircle, round the western and southern sides of a long irregular spur projecting from the *ghât* range. Continuing to cling to some portion of this spur, and gradually mounting by a stiff gradient of 1 in 40, the line at the 10th mile reaches a narrow neck of hill connecting it with the main *ghât* cliffs. At the end of this neck the reversing station is placed, 1349 feet of the total height being now surmounted, leaving 482 feet to be still climbed in the last 4½ miles before reaching the crest of the *ghât* at Lanowlee. Returning to the bottom end of the incline, the railway, after passing some exceptionally heavy embankments in the 2d and 3d miles, traverses a group of six tunnels, the longest of which is 429 feet, and is then carried over the remaining distance to Thakurwada station in the 6th mile by a series of formidable works. Here, in a length of 2 miles, occur eight considerable tunnels and five lofty viaducts. The largest of these tunnels, through hard trap rock, is 1305 feet, the remainder being from 147 to 873 feet. The viaducts are of masonry, having four to eight arches of 50 feet span, the piers reaching 77, 98, 129, and 143 feet in height above ground. Beyond Thakurwada the railway, following a south-east line, is carried for some distance along a natural bench or step on the hill-side, without meeting any serious obstacle. Reaching the 8th mile, it is passed over two ravines by two viaducts of six 40-feet, and four 30-feet arches, having piers 48 and 88 feet high, and continuing along the same bench, in the succeeding

2 miles it traverses nine tunnels, the longest of which is 846 feet, situated in the 10th mile. The line, still on grades of 1 in 40 and 1 in 50, passes along the neck of hill joining the long spur up which it has hitherto climbed with the main *ghât*, and reaches—after passing over another viaduct of one 60-, and ten 40-feet arches—the reversing station of Battery Hill. Leaving the reversing station by the sharpest curve on the incline, viz., that of 15 chains radius, on a grade of 1 in 75, the line pierces the projecting bluff of a solid basalt hill by a tunnel 1023 feet long, and now enters the great gorge or ravine down which flows the main stream of the *ghât*. Winding up the side of this ravine, and clinging pertinaciously to its southern flank, the railway climbs by a stiff gradient of 1 in 37, the 1 mile 38 chains leading to the short comparative bit of level at Khandalla station, passing on its way through another rock tunnel 126 feet long, thence by lesser gradients of 1 in 40 and 1 in 50 it mounts the remaining 2 miles to the summit of the Bhore, at Lanowlee.

The works on the Bhore *ghât* incline comprise twenty-five tunnels of a total length of 3986 yards, or over 2¼ miles, the two longest being one of 435 yards—or 1305 feet—and one of 341 yards—or 1023 feet—in length, carried without a shaft through a mountain of basalt. Generally, from the rugged character of the cliffs, it was rarely possible to sink summit shafts, and the tunnels had to be driven from the two ends. Being always on steep gradients, and often on sharp curves, the most careful and accurate setting out was necessary in order to secure a true junction of the headings. There are altogether on the *ghât* eight lofty viaducts of arched masonry, having a total length of 2961 feet, or over half a mile. The two largest are 504 feet long, having a maximum height of no less than 160 and 163 feet above foundations. Of smaller bridges there are twenty-two of spans from 7 to 30 feet, and eighty-one culverts of various size. The construction of this barely 16 miles of mountain railroad occupied seven and a quarter years, and it cost £1,100,000. The average number of labourers and workmen of all kinds employed during two seasons was 25,000, and in the year 1861 upwards of 42,000 men are stated to have been engaged on the works.

Among the many peculiar difficulties encountered, both on the Bhore and on the Thul *ghât* inclines, were the unhealthy nature of the hot and rainy seasons (the latter with a rainfall of 200 inches), and the fatal epidemics which so often scattered and dispersed the armies of men engaged; the rugged and precipitous character of the ground, impeding the haulage and transport of material, and harassing all engaged on the operations; the sudden and dangerous landslips from the hill-sides, and the extreme hardness and solidity of the trap rocks so largely dealt with; the scarcity of water at certain periods of the year, and the difficulty at all times of providing the ordinary necessaries and comforts of the workmen. There are probably but few travellers now daily passing up and down the magnificent Thul and Bhore *ghât* inclines, quietly seated in comfortable railway carriages, who can at all adequately realise the extraordinary nature of the obstacles which have been so successfully overcome, and the great skill and daring of all those engaged—especially during the first years—in shaping and carving out of the rocky mountain sides those wide luxurious roads on which they now so easily and securely travel. To form a true conception of their surprising magnitude, it is necessary to pass along them either on foot or by open trolly, closely observing all the numberless ingenious expedients resorted to for making the rough ways smooth, and converting the stupendous natural inequalities of the precipitous hills into a series of uniform inclined surfaces, as well as closely regarding from below and from above the details of the towering embankments and masonry viaducts by which the low parts have been filled up, and the constantly recurring wide and spacious tunnels, or deep rock-cuttings, by which the projecting mountainous ridges and bluffs have been brought low; until the whole rugged and inhospitable region has been smoothed down, and rendered easy and secure for the daily transit at all seasons of railway trains crowded with men and merchandise.

From Lanowlee—where the railway has at length gained the summit level of the Western *ghâts*—the course followed by the south-east extension of the Great Indian Peninsula line is *viâ* Poona and Sholapore to Raichore, where it joins the

Madras railway at 409 miles from Bombay. For the first portion of the distance it traverses a somewhat rough country, with a ruling gradient of 1 in 131, but for the most part the works are of an ordinary character. Crossing the rivers Bheema and Seena by two bridges—the first of twenty-eight masonry arches of 40-feet span, with piers 60 feet high, and the second of twelve similar arches, with piers 54 feet in height—the line, a short distance before reaching Raichore, crosses the Kistna, a stream of considerable magnitude, by a girder bridge 3855 feet long, consisting of thirty-six clear spans of 100 feet each, with piers formed of iron cylinders filled with concrete, 49 feet high above the lowest water. The piers and abutments of the Kistna bridge have been constructed for a double line; the superstructure carrying a single line only, and the completed cost of the structure is given as £127,300.

The total length of the Great Indian Peninsula system of main lines and branches is 1288¼ miles. The north-east main line as far as Khandwa, 352 miles from Bombay, is laid double, as well as the 60 miles from Bhasavul to Sheogaum on the Nagpur branch. On the south-east trunk line the rails are double for a distance of 46 miles from Callian, making in all 459 miles of double track. On the rest of the railway the earthworks are for the most part made for a single, and the masonry of bridges and viaducts for a double, line of way. The rails originally laid were of iron, weighing 68 and 84 lbs. per yard, these are now being gradually replaced by steel rails of 69, 82, and 86 lbs. The sleepers, which were originally of wood, are also being largely replaced by iron bowls. As far as Sholapore the line was opened in sections at various times, being completed to that town in June 1860. The extension beyond Sholapore, to meet the Madras railway at Raichore, was delayed; not being commenced until the year 1865, and the permanent bridge over the Kistna river, near the end of the section, was opened for traffic in October 1873. The Great Indian Peninsula Railway Company, in addition to their own lines, work, under contract with the Government, the Dhond and Munmar State Railway, the Berar branches, and the Wardha Valley State Railway, which opens up a valuable coal field at Warora, in the Central Provinces.

Madras Railway.

The original portion of the 'Madras Railway' system of lines was, as we have seen, that to the south-west, from the city of Madras, through Arconum and Menil, to the opposite sea-coast near Beypoor (now extended to Calicut). From this trunk line an important branch, 87¼ miles long, extends to Bangalore, and one of 26 miles to Ootacamund. The first sod of this railway was turned on the 9th June 1853, the intention being to construct an 'experimental' line from Madras to Menil, a distance of 50 miles, but before this length was completed it was decided to extend the railway to the western coast, and the final contract was accordingly signed in 1855. The distance from Madras to Beypoor is 406 miles. The line, leaving the terminal station at Madras situated almost on the sea-beach, passes Arconum, the junction station for the Bombay line, at 42 miles, and traverses the width of the peninsula without encountering any serious engineering obstacles. The range of Western *ghâts* on the opposite coast is passed by the gap at Palghat, at a point only 800 feet above the level of the sea, and affording a fairly easy descent to the sea-coast.

Following now the section of the Madras railway connecting with Bombay: Shortly after leaving Raichore, and the Great Indian Peninsula Railway terminating at that place, the line encounters the large Tungabudhra river, which it crosses by a girder bridge 4060 feet long, consisting of fifty-eight spans of 64 feet each. Running almost due south, it traverses a moderately easy country, and reaches the junction station of Guntakal—now an important centre and meeting-point of an extensive system of narrow-gauge lines in the Madras Presidency. Here the Madras railway trunk line bends to the south-east, and after passing over about 25 miles of rough and hilly country approaches two important rivers, viz., the Penner and the Chitravati, which it crosses by two fine bridges lately reconstructed, one 1830 feet long, opened in 1889, of thirteen girder spans of 131 feet each, with foundations 54 feet below the lowest water; the other, 2670 feet long —opened in 1890—of nineteen girder spans of the same size, with foundations 78 feet below low water. The respective cost of these bridges is approximately £112,000 and £136,000. Several other streams of some magnitude are also shortly after-

wards encountered, including the Papaghni river, over which a large girder bridge of fifteen spans of 131 feet is now in course of construction, in replacement of an earlier structure. A few miles beyond Cuddapah the railway reaches and crosses the river Cheyer by a long bridge of 3500 feet, costing £124,500, and consisting of fifty spans of 64 feet, with a maximum depth of foundations of 100 feet. From the Cheyer river to the junction with the Madras Beypoor (Calicut) railway at Arconum, 42 miles from Madras, the line traverses a hilly country, cut up with ravines, and necessitating much heavy embankment and rocky cutting, but containing no works of more than average importance. The total length of the Madras Railway system of lines as now open is 839¼ miles, of which the length from Raichore to Arconum is 307½ miles, the remainder belonging to the south-west system.

The weight of the rails on the Madras Railway vary from 65 to 84 lbs., laid on iron bowl sleepers. Originally the south-western section was laid with wooden sleepers, and an experiment was made of using stone blocks 2′×2′×1′ in their place; these were, however, soon discarded, and in 1861 the jungle-wood sleepers first used were replaced by cast-iron bowls, which are now almost entirely employed.

The early history, general alignment, and principal constructional features of the three parent lines of the Indian railway system, viz. the 'East Indian Railway,' the 'Great Indian Peninsula Railway,' and the 'Madras Railway'—aggregating 3653 miles—have now been succinctly traced. It would be neither agreeable to the reader, nor suitable to the limited compass of this volume, to attempt to follow in similar outline the development and course of the remaining 14,000 miles of the existing railways in India. It will, in the succeeding chapters, be sufficient for the main purpose in view to illustrate, with greater or less particularity—according to relative importance—only those great works of the first magnitude and interest which are to be met with scattered over the country on the various lines of railway, reserving for a concluding chapter a *résumé* of such of the general aspects and statistics of Indian railways, considered as a whole, as may be of general interest.

CHAPTER X

REMARKS, GORAI BRIDGE, DUFFERIN BRIDGE

Preliminary observations on some of the peculiarities and circumstances of Indian rivers—Position of bridges—Design affected by character of the river—Arched masonry bridges—Conditions rarely suitable—Iron structures—Bridge piers and abutments—Determination of minimum waterway—Security of bridge abutments—Training works—Selected examples of large or interesting railway bridges in India—The bridge over the Gorai river, Eastern Bengal Railway—Particulars and details of construction—Sinking the cylinders—Floating the girders into position—The Oude and Rohilkund Railway—Outline of system—Particulars of bridges over the Ganges—The Dufferin Bridge at Benares—Descriptive details of design—Erection of the bridge—Preliminary work—Sinking the main pier caissons—Great depth of foundations—Accident at No. 4 pier—Remedial measures—The minor piers—Erection of superstructure, and completion of the work.

The selected examples of large railway structures in India, illustrated in this and the following chapters, are almost entirely confined to iron or steel bridges of some magnitude, carried over the great rivers of the country. It will serve, therefore, to the greater interest of the reader, as well as to his better appreciation of the more difficult problems occasionally to be solved in connection with large bridge construction in India, to preface this chapter with a few preliminary observations on some of the special peculiarities and circumstances of Indian rivers, as affecting the general features of the design and location of large railway bridges. In making these observations, however, no attempt is made to treat in a comprehensive manner so exceedingly important and difficult a subject; the observations are confined to the indication of a few broad general features of bridge location and design, suited to the general reader.

In selecting the exact spot for bridging a large river, the

engineer is usually restricted to very moderate limits of deviation from the direct route proposed to be taken by the railway. Within such limits he will seek for some portion of the valley where the main channel of the river is not only concentrated, but where, from all reliable indications, it appears to be fixed in a permanent manner. Failing the discovery of such a position, some more or less considerable outlay will be necessary for regulating the channel and preserving the permanency of the bed, by means of artificial training works. The whole design of the contemplated bridge will in great measure be governed by the character of the river bottom at the point selected for the erection of the structure. In ordinary cases where permanent rock, or other sufficiently hard strata, occurs on the surface, or is placed within easy reach below water, and where suitable building materials are obtainable at ordinary expense, a bridge with masonry piers connected by stone or brick archwork will probably be the most economical in first cost; and, if so, will certainly be the most convenient, the most pleasing, and altogether the most desirable construction. A well-designed and well-built arched masonry bridge, once made on a secure foundation, entails little or no subsequent expense, and the line of railway laid over it is free from the many inconveniences arising from the contraction and expansion of large iron or steel superstructures. The heavy expense of frequently painting the iron girder work to avoid corrosion ; the liability to slow deterioration under the constant inherent motion of its parts, and the vibration of passing trains, together with the rattling noise experienced under the traffic, are great drawbacks in the case of all iron or steel structures. In the plains of India, however, the conditions necessary for security and economy in the erection of arched masonry bridges of large size are rarely met with, for in all cases where the expense of pier foundations reaches beyond a certain proportion, economy in first cost has to be sought by increasing the width of opening, so as to limit the number of the piers, and thus the size of span soon extends beyond the practical limits of arch-work. Bridge piers and abutments, in the great majority of cases, are constructed of stone or brick masonry, but the use of iron for piers, as well as for the

superstructure of bridges, is sometimes imposed by local conditions, amongst others, by any special liability of the district to earthquake.

The determination of the minimum waterway to be allowed in the case of bridges over the larger class of rivers, especially in the great alluvial plains of upper India, is attended with many peculiar difficulties. As a rule, little or no means exist of ascertaining the true area of the basin drained by these rivers, especially if liable to receive spill water from other river basins. Moreover, the areas are usually so enormous, and subject to so many fluctuating conditions of rainfall, and physical constitution, and the problem is complicated by so many highly variable conditions, each affecting in some degree, and some largely, the maximum flood discharge, as to place its theoretical calculation at the best on a very empirical and uncertain basis. In these circumstances the engineer, naturally solicitous above all for the permanent stability of his work, is apt to err on the safe side, and provide for a greater area of waterway than necessary, rather than incur the risk of unduly contracting the limits of the highest recorded flow in the river during high floods.

It is rare in the plains of India to find a river flowing within well-defined banks. A tolerably permanent high bank may often be found on one side, behind which one abutment of a bridge may be securely placed. The proper position for the further abutment then becomes the difficult problem. In such cases the main channel will invariably be found nearest the high and more or less permanent bank, and the main openings of the bridge will of course be there provided; a less expensive structure being designed as a continuation of the main openings for such distance over the opposite low ground as may be deemed necessary for security. In all cases where the piers and abutments of a bridge can be rendered perfectly secure against scour, and capable of withstanding the concentrated force of the severest floods, at a less cost than increasing the lineal waterway of the whole structure, the length of the bridge will be safely contracted, and the river will be largely permitted to adjust its own sectional area to the discharge, which it will do by scouring away its bed to the extent

necessary; but in frequent practice the increased cost of protection and of training works thereby entailed, will exceed the saving due to shortening the bridge. Every bridge site in the great plains of India possesses, in fact, so many special and peculiar features of its own, that the determination of the waterway to be allowed is only very partially reducible to general principles, or to considerations applicable in all cases. The two important objects which the practical engineer will always have in view, and which will mainly govern his designs, will be the perfect security of the bridge abutments, and the establishment, by suitable training works where necessary, of a permanent and well-defined channel, for some distance above and well through the site of the bridge, evenly embracing its waterway, and constraining the passage of the water through the whole width of the work, with a fairly uniform velocity of current.

It is now necessary to select for the purpose of illustration a few additional examples of large, or otherwise interesting bridge constructions occurring on Indian railways, out of the very numerous sum-total of such works, the latter comprising very many of scarcely inferior proportions to those which the space at command permits detailed mention.

On the Goalunda extension of the Eastern Bengal Railway, between the years 1867 and 1870, a bridge was constructed over the Gorai River, which, although not a work of especially remarkable size, is an interesting example of construction carried out, under peculiar conditions, by the application and employment of special methods. The data for the following description of this bridge is collected from a very full paper on its construction, read before the Institution of Civil Engineers by its designer and builder, Sir Bradford Leslie, K.C.I.E., M.I.C.E.[1] The Gorai River is the largest and most important of the many arms or branches into which the Ganges is broken up on reaching its delta at the head of the Bay of Bengal. At the site chosen for the railway-crossing, the river in the dry season is about 1000 feet wide, with a depth of 40 feet of water, but during the rainy season the width reaches 1600

[1] *Vide* vol. xxxiv. *Min. Proc. Institute of Civil Engineers.*

feet, with a flood rise of 28 feet, and a velocity of current of nearly 5 miles an hour, at which time the bed is scoured out some 24 feet, so that the body of water then reaches over 90 feet in depth. The alluvial deposit forming the bed of the river consists of a light sandy clay and loam, followed by a stratum of stiffer clay overlying a coarse grey sand.

The railway bridge thrown across the Gorai consists of seven main girder-spans of 185 feet each. On the west side, beyond the seven main spans, a raised portion of the river bed—covered, however, by 30 feet of water in floods—is crossed by a cast-iron screw-pile viaduct, of nine spans of 46 feet 3 inches, so that the total length of bridge and viaduct construction is 1744 feet. Each pier of the main bridge is composed of two iron cylinders, placed 37 feet 6 inches apart from centre to centre; this width being sufficient to allow for a double line of rails if required. The cylinders are sunk to a maximum depth of 98 feet below low water (those forming the land extremities being sunk to the same depth as those in mid-stream), and the total depth to which the foundations were sunk was determined with reference to the amount of scour anticipated. The lower portion of each cylinder, for a height of 30 feet 6 inches, is built up of wrought-iron rings, each 4 feet 6 inches high, bolted together by internal flanges, and is 14 feet diameter at the bottom—where the lower edge is strengthened to form a strong cutting edge—and 13 feet 4 inches at the top. Above the wrought-iron portion, a cast-iron conical piece narrows the diameter to 10 feet, and the upper length of the cylinder is formed of cast-iron of this diameter; the cast-iron portion being put together in rings of four segments, each 9 feet high. The separate segments are bolted together by means of internal projecting flanges, leaving the piers smooth on the external face. When completed, the pier cylinders were filled in with concrete and brickwork, and were joined together at the top by two wrought-iron connecting girders, which serve to carry the main girders of the superstructure, at a height of 50 feet above low water. The superstructure girders are solid beams, 12 feet high, and 3 feet wide on the top and bottom members, placed 13 feet 6 inches apart in the clear, so as to carry a single line only. The interesting features of the Gorai

bridge are to be found in the methods employed in its erection, both in sinking the pier cylinders, and in the emplacement of the girder superstructure.

The treacherous nature of the river-bed, and the depth and strength of the current, made it undesirable to attempt the work of sinking the cylinders by the aid of temporary fixed stagings. A pair of floating pontoons, each 140 feet long by 30 feet wide, joined together by a platform 17 feet in width, containing the necessary openings for the two cylinders, were therefore provided. The pontoons were furnished with powerful overhead travelling cranes, engine power, and all the necessary gear for manipulating the heavy weights that would have to be dealt with, and were securely anchored into position at the site of each pier. Three lower rings of cylinder, in all 12 feet 6 inches in height, and weighing 30 tons, were erected on timbers placed across the opening in the pontoon platform, and a temporary water-tight bottom of pine staves was inserted at some distance above the lower edge. An inner lining of brickwork, supported on the projecting ring flanges was also commenced. The depth of water in the river was too great to allow a sufficient length of cylinder to be slung and lowered so as to reach the river-bed in one operation, hence the necessity of the temporary bottom to render the tube buoyant and self-supporting. Three lower rings were suspended and lowered into the water, and the tackle to be used for controlling and adjusting the position of the cylinder in going down, was fitted. Successive rings were then bolted on, and the internal lining of brickwork was continued, adding weight until the cylinder was sunk into, and was steadily buoyed up by the water, so that it could now be freed from the suspending chains. By adding fresh rings, and building additional brick lining, the process was continued until the bottom of the river was reached, when the interior of the cylinder was filled with water. The temporary water-tight bottom was now battered out, and the cylinder was allowed to sink into the soft soil of the river-bed until supported by it. The operations for pitching the pier cylinders were carried out with only one mishap, caused by a cyclone which occurred in 1869, and in consequence of which the lower portions of two cylinders were

overthrown and submerged; one of these was, however, recovered, but the other was permanently lost, and had to be replaced.

The sinking of the cylinders through the alluvial soil of the river-bed to the requisite depth, was effected by excavating the earth from the inside of the cylinder by a rotating boring tool 9 feet in diameter, consisting of a disc fitted with blades and cutters. The boring-tool was slowly revolved by a compressed-air engine placed above, through an intermediate vertical shaft, formed of a pipe 13 inches in diameter, placed inside another line of piping 26 inches outside diameter; the annular space between the two pipes being divided into a series of air-jackets, making a hollow working shaft of great strength, and practically self-supporting in water. The object of this ingenious hollow shaft was for the purpose of removing the earth by a strong current of water constantly flowing up the central pipe. To establish this current, a 12-inch syphon pipe was provided, the inner leg of which was immersed in the hollow boring shaft, and the outer leg into the water in the river. The air was exhausted from the syphon pipe, and being replaced by water, a blow from the bottom of the cylinder, up the shaft, and out by the syphon, was at once set in motion; in quantity proportionate to that discharged into the cylinder by a pair of 13-inch centrifugal pumps. The soil of the river bed, loosened and churned by the boring head, was discharged together with the water, and by this means the cylinder was gradually made to sink. The necessary additions to the length of the pipe-shaft and the readjustment of the syphon, were made from time to time, until the designed depth of sinking was reached. The land cylinders, which were pitched in the dry season, were sunk, by a modification of the same method, through about 120 feet of the alluvial soil of the river-bed, the necessary water being supplied by pumping.

The cylinders forming the piers being sunk, and finished off at the requisite height of 50 feet above low water, the first main girders of the superstructure were erected and riveted up complete, in two parallel rows on the embankment of the east approach to the bridge, and were rolled forward into position by means of two powerful overhead lorries, from

which, by the aid of overhead lifting gear, the girders could be suspended. The lorries were furnished with flanged wheels to run on rails, by means of which they could be moved to and fro, whilst the weight was off them, but when the weight was lifted and suspended, the two trollies carrying it were moved forward on series of 3½ inch iron-bar rollers, each 10 feet long, placed between the iron-shod sills of the lorries and the rails. The first span of the bridge being dry, the girders were hauled into place over a temporary staging between the piers. This span was completed, and the railway was laid at its proper level on the flooring girders; the temporary line on the approach embankment being at the same time raised to the necessary height. The six remaining girder-spans were then erected, and had to be launched over the water; this was done by floating the forward end of the girders on a pontoon furnished with carrying shears of the necessary height, the after end being carried by the lorries.

The pontoon carrying the forward part of the load was warped across the stream by the aid of suitable tackle, devised for the purpose, and provision was also made for adjusting and maintaining it in proper alignment during the operation. In carrying out this system of launching, provision had to be made for a possible considerable variation in the water-level. To meet this contingency, the height of the supporting shears carried by the pontoon was made adjustable, and it was further arranged that when the forward end of the girders was floated over the pier on which it was to be landed, the amount of lowering required should not exceed 12 inches, and this degree of lowering was effected by admitting water into the pontoon and sinking it to the required extent. Numerous precautions were also necessary to secure a sufficient lateral strength and stabilty of the moving girders in case of high winds, which would act against an exposed surface of 2400 square feet, and to properly distribute the weight of about 65 tons borne by the pontoon. These various delicate operations connected with the launching and placing of the main girders were rapidly and successfully carried out without the smallest mishap.

The first pier cylinder was put into the water in November

1867; and the whole bridge was completed, at a cost, including protection works, of £148,375, by the end of the year 1870. The average time occupied in launching the girders across the water-spans was about one hour, and the whole superstructure of the seven main spans was erected and placed in position in seven weeks and three days.

The late Oude and Rohilkund Guaranteed Railway Company, whose various undertakings were taken over by the Government under the contract terms in 1889, constructed a system of broad-gauge lines situated almost entirely north of the Ganges river, and opened up the rich tracts of country in Oudh and Rohilkund, lying between Benares on the east, and Saharanpur on the north-west. The company, which commenced operations in a somewhat humble manner, as the 'Indian Branch Railway Company,' in the year 1864 entered upon the construction of a short branch line from the left bank of the Ganges opposite Cawnpore to Lucknow, a distance of 45 miles, and subsequently, under its old or new title, gradually extended lines of rail from Lucknow eastwards to Fyzabad and Benares, and north-westwards through Bareilly and Moradabad to Saharanpur, ultimately developing, with branches, a system 692½ miles long. From the isolated position of these lines, cut off entirely from the East Indian and other railways south of the Ganges, the company was soon constrained to connect itself with the general railway system of India, by throwing bridges over the sacred river of the Hindus, and this in no less than four places. No other railway company has as yet anywhere bridged this river, unless the East Indian Railway Bridge over the Hooghly channel, near Calcutta—already referred to—is considered to be a Ganges bridge.

The two earliest bridges carried over the Ganges by the Oudh and Rohilkund Railway Company, were those situated at Cawnpore and Rajghat, both on branches, the first connecting Lucknow with Cawnpore; and the second connecting the upper districts of Rohilkund with Aligarh on the East Indian Railway. The first of these bridges, viz., that at Cawnpore, is 2830 feet long, and consists of 25 deck girder-spans (with cart-road below) of 100 feet each, and 2 of 40 feet. The girders are carried at 32 feet above the lowest water; and the piers

are founded on single 18-feet wells, sunk to a maximum depth of 65 feet below the same point, into the sandy river-bed. The Rajghat Bridge, which is 3040 feet long, has 33 deck-spans of 80 feet, placed 24½ feet above low-water, and single 12½ feet foundation wells sunk 55 feet. These bridges cost £174,700 and £79,820 respectively—the latter being one of the cheapest structures of its size yet made. The third bridge over the Ganges is on the main-line extension of the railway from Moradabad to Saharanpur, at Balawali. This fine and relatively recent work—opened early in the year 1887—is 2904 feet long, and has 11 clear spans of iron girders, carrying the roadway between them, of 248 feet each, or 264 feet centre to centre of piers, placed 40 feet above the level of lowest water. The piers are carried on double circular wells 20 feet in diameter, sunk to a depth of 100 feet below low water in pure sand. The finished cost of this bridge was £277,271.[1]

The latest, largest, and most important of the railway bridges erected by the Oudh and Rohilkund Railway Company over the sacred Ganges, is that situated immediately below the town of Benares, called the 'Dufferin' Bridge, in honour of the Earl of Dufferin, during whose Vice-Royalty it was constructed, and by whom it was officially opened in September of the year 1887. This splendid work is undoubtedly in some respects the most perfect specimen of railway bridge engineering in India, and a short description of it will be of more than ordinary interest. The following account of the Dufferin Bridge is chiefly drawn from official records, and from a very full descriptive paper on its construction read before the Institution of Civil Engineers on the 4th March 1890.[2]

For many years after the Oudh and Rohilkund Railway Company had completed its line north of the Ganges to Benares, and to a point on the left bank of the river, situated opposite the terminus of a short branch of the East Indian Railway, from their main line at Mogul Serai, a cart service was main-

[1] For true cost of these and other railway bridges stated in Indian rupees, see Appendix K.

[2] *Vide* vol. ci. *Min. Proc. Institute of Civil Engineers.*

tained across the intervening river by means of a temporary bridge of boats. In the year 1879 it was determined to connect the two systems of lines on either bank by a permanent bridge over the formidable channel of the Ganges lying between them. The construction of the bridge was approved by the Secretary of State for India in July of that year, and active steps were at once taken to prepare alternative plans and estimates for a combined railway and road bridge, on the site which had been already selected by the chief engineer of the company.

The engineers had to decide upon the most suitable and least expensive manner of throwing a railway bridge over a river with a bed consisting virtually of pure sand extending to an unknown depth, carrying a dry season body of water about 1800 feet wide and 37 feet in maximum depth, and liable to a rise of 50 feet during the highest floods, at which times the water, overtopping the low right bank of the river by some 7 or 8 feet, inundates the country for 5 or 6 miles inland. On the left-hand side the river-bank is high, and is not liable to be overtopped. During the greater part of the dry season the velocity of the current is moderate; but during high floods it reaches 15 miles an hour, and the sandy bed of the river is then sometimes scoured to a depth of over 30 feet, giving a possible depth of water in full flood of no less than 120 feet in all. In order to allow ample headway for the free passage of the river navigation, it was decided that the underside of any structure that might be designed should not be placed at a lower level than 75 feet above the lowest water in the river—or 25 feet above the top of the maximum floods. The principal points which the engineers had first to determine were: the total length of bridge waterway, and the size of the individual spans; the description of pier, the depth of foundations necessary—considered in reference to the extreme limits of scour—and the general design and character of the superstructure, so as conveniently to utilise the bridge both for the railway and for ordinary wheeled traffic, and further—the general data for the contemplated work being settled—it was necessary to decide upon the most practical, as well as the most economical and expeditious methods of construction,

whether as regards the sinking and founding of the piers, or for the erection of the superstructure.

These initial questions were, after full investigation and discussion of various alternative proposals, finally settled as follows:—The total open water-way of the bridge was fixed at 3507 feet, made up of seven large spans of 356 feet each, carried over the deep channel of the river, situated towards its left and permanent high bank, and nine extension spans of 114 feet each, to pass over the raised portion of the river-bed lying beyond the right dry-season bank. It was decided that the piers should be founded on single elliptical blocks of brickwork, pierced with three excavating chambers, and enclosed in an iron shell or caisson sunk into the river-bed. Moreover, in consideration of the limits of scour in high floods—so far as yet observed—it was deemed necessary that the foundation caissons and blocks should be sunk in the pure sand to a minimum depth of 120 feet below low-water level—that is to say, to 83 feet below the ordinary dry-season bed in its deepest part—but that this depth of foundation should be increased, if careful soundings taken during extreme floods, should indicate in the course of operations, that the bed was likely to scour to a greater depth than 33 feet below the deepest dry-season bed—or 70 feet below low-water-level.

With regard to the superstructure, it was determined to employ girders constructed entirely of steel, this being at the time the largest proposed application of steel for structural purposes. The larger girders were designed of the compound triangulated type, 355½ feet in length, and 35 feet 4½ inches in depth; the smaller girders 113 feet 8 inches in length, by 11 feet 5¼ inches in depth, and it was agreed that the roadway both for rail and for cart traffic should be carried on the same level, between the large girders, and over the top of the smaller extension spans. The height of the bridge and the depth of the main girders being so great, and the right bank of the river being so low, it was not considered economically practicable to arrange a separate road for ordinary wheeled traffic, it became necessary, therefore, to provide a metalled road 22 feet in width—supported on strong buckled plates, on the same level as the rails, to be used for such traffic in the intervals

between the passage of trains, and to place footways for pedestrians 5 feet wide, carried on cantilevers outside the main girders.

Several schemes were proposed for getting the huge main spans of girderwork into position—such as floating them into place by the aid of pontoons, or raising them from near the water level by hydraulic lifts simultaneously with the building up of the piers themselves, and some others. All these plans were, however, discarded, as in one manner or another open to practical objection under the circumstances of the river, and the girders were ultimately built up in place—in spite of the deep water in the channel—on very cleverly arranged stagings of full height, erected on the river-bed between the piers.

Practical work on the construction of the bridge commenced on the 19th January 1881, being started simultaneously at the two abutments—placed 3507 feet 3 inches apart—and operations for the most part of each working season were subsequently carried on by night as well as by day, by the aid of powerful electric lights. As a preliminary, it was necessary that the distance between the two abutments of the bridge should be very exactly measured. This measurement was effected in the following manner: first, two lines parallel with the centre line of the work were ranged, each 85 feet on either side of it, so that these lines being always clear of obstruction during the progress of the work, the intermediate measurements could be made and transferred from them. To ascertain the exact total length, the portion on the dry bed was levelled, and the measurement was made by steel tapes: that across the deep water channel—a distance of about 1800 feet at low water—was first fixed by a trigonometrical triangulation, and then by a fine steel wire stretched across the channel, over pulleys exactly 20 feet high above water level. The wire was strained by weights until it exactly touched the water surface in the centre, and fixed points on either bank were then plumbed up to the wire and marked on it by solder marks. The wire was now carried on shore, and being fixed and strained in precisely the same manner over a truly levelled piece of ground, the exact distance could then be directly measured. This measurement was found to be within an inch of that trigonometrically deter-

mined. Subsequently, when the work carried on from either end of the bridge was joined near the middle of the river, an error of a little over $\frac{1}{2}$ an inch was detected.

On the Benares, or left-hand side of the river, the approach line of railway crosses the Rajghat plateau, where in former years there had been a strongly fortified post, to command the river, crossing from the Grand Trunk road. 'Tradition assigns to this naturally very strong position a great antiquity, and points to it as being the site of the stronghold of the ancient rulers of the once mighty kingdom of Benares, which is said to have extended from the borders of "Chin" (Thibet) to Malwa, and from the sea to within ten days' journey of Lahore.' The British fortified post on the plateau was abandoned in the year 1865.

The piers of the Dufferin Bridge, carrying the large 356 feet girder spans, were founded on single elliptical wells 65 feet long, and 28 feet wide. The iron foundation-caissons varied in height to suit the depth of water through which they had to be sunk, the largest was 50 feet high, others being 42 feet and 26 feet respectively; they were constructed of iron plates $\frac{1}{2}$ inch and $\frac{3}{8}$ inch thick, with inner and outer shells 5 feet apart, connected together by horizontal and cross bracings. From the base of the outer shell, the inner shell inclined at an angle of 45 degrees, up to a height of 6 feet, thus forming a strong cutting edge which was further strengthened by a cast-steel shoe. The interior wedge-shaped space thus formed at the bottom, between the two shells, was at first filled in with cement concrete, but it was afterwards found preferable to use pure sand only. The caissons were divided into three internal excavating chambers, by double cross walls also furnished with tapered cutting edges, situated about 6 feet above the base of the caisson. On the top of the caissons, midway between the inner and outer shells, an iron crating of angle bars, well tied together, was framed, which served to strongly bind together the brickwork of the foundation blocks and the upper brick-work of the pier. The system adopted in sinking through the water was briefly as follows. The first 10 feet of the caisson having been built on a temporary platform, between a pair of iron floating pontoons coupled together at a distance of 32 feet

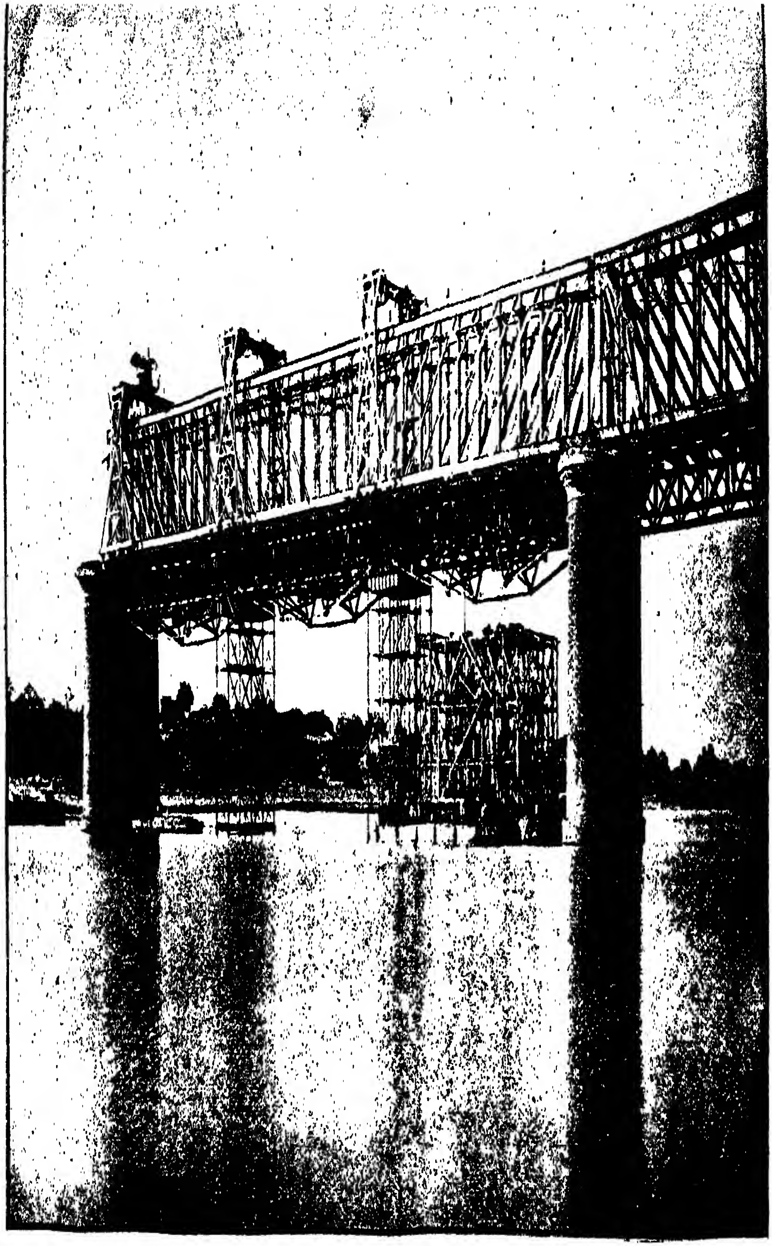
apart, and strongly moored into position, were lowered by chain slings into the water by the aid of powerful tackle. Additional sections were added to the top of the caisson, and it was gradually lowered; the weight being augmented by the concrete and brick linings, until the lower cutting edge reached, and was adjusted in its true position on the river-bed. The suspending chains were then released, the interior brickwork was brought up to a height of about twelve feet above water-level, and the pier was now ready for sinking. The sinking through the river bed was effected by mechanical diggers 8 feet in diameter, working in the three excavating chambers. Each digger weighed $3\frac{1}{4}$ tons when empty, and contained 130 cubic feet of material when full, then weighing about 6 tons more. They were worked by steam travellers carried on an overhead staging 57 feet in height erected on the pontoons, each capable of lifting 20 tons. The material lifted by the diggers was deposited into shoots at the side of the pontoons, and discharged into the river. By this means rather under one foot, or at the rate of 1·43 feet per day whilst the diggers were in action, of sinking was effected; the elliptical pier blocks being sunk at that average rate per working day.

The foundations of the seven piers for the main spans were carried down to varying depths below the water-level. The first three on the left bank of the river were secured into a bed of firm yellow clay at a moderate depth, but piers Nos. 4 and 5—the first of which has the deepest foundation in the world—were forced down through sand to the great depth of 141 and 140 feet below low water, or about 104 feet below the deepest dry-season bed; these piers being thus no less than 215 feet in height from the bottom of their foundation to the underside of the girders. During the operation of sinking the piers, many interesting and curious objects: ancient relics, as well as animal remains, were met with, which were carefully collected and preserved, the position and actual depth at which each article was found having been precisely recorded.

The work at No. 4 pier was seriously hampered by an accident (the only serious one which occurred during the progress of the works) which might have entailed an enforced modification of the bridge superstructure. The lower cutting

edge of the iron caisson,—which in this case was 26 feet in height—had reached a thin bed of clay situated about 50 feet below the river-bed, or 70½ feet below low water, and the masonry had been built up to a height of 91 feet, so as to add as much weight as possible. The diggers had excavated holes into the clay, about 9 feet below the lower edge of the caisson, when a considerable portion of the side of the hollow excavation suddenly fell in, displacing a large volume of water, which was consequently forced upwards through the excavating chambers, and overflowed the top of the brickwork. The sudden and violent pressure of the water burst the sides of the pier masonry, which, being new, and the mortar not having properly set, was fractured in two lines from the top down to within a few feet of the top of the caisson. As the rainy season was then close at hand, nothing could be immediately done, and it was at first feared that an almost irremediable disaster had occurred. As soon, however, as the floods had subsided, it was found that the fractured portion of the brickwork, 62 feet in height, 46 feet in width, and extending 21 feet below the river-bed, had fallen away, and thus the difficult operation of its removal by explosives or other means, was obviated. To remedy this serious injury to the pier, the engineer in charge of the work, with ready resource, devised a double wrought-iron shield of exact size and shape to enclose the gap. This shield was rapidly constructed at the site of the works, and was sunk through the bed of the river, down to the base of the fracture, by means of dredgers working within it; and when the broken surfaces of the brickwork had been trimmed and cleaned, and the shield was correctly fitted into place, the interior space was filled in with cement concrete, and the top of the patch was strongly bonded with iron rails into the old work. By this ingenious and thoroughly successful expedient the pier was rendered virtually as strong as ever, and the whole was afterwards sunk 70½ feet deeper than it was at the time of the accident.

When each pier had been sunk to its proper depth, the three excavating chambers were filled in solid with concrete, and plugged at the top with brickwork. The foundation masonry was built up to a few feet above low water, and was



'DUFFERIN' BRIDGE OVER THE GANGES AT BENARES, IN COURSE OF CONSTRUCTION.

spans were successively completed and the temporary staging was no longer required, the 114-feet girders were removed by the pontoons, and carried to shore, where they were then completed, and lifted bodily into their final place by derricks. The weight of a pair of main girders is 491 tons, and that of a main span complete is 746 tons, or 5222 tons of steel-work in the seven larger spans of the bridge. The extension spans weigh 127 tons each, or 1143 tons in the nine spans, making 6365 tons in the whole bridge. The cost of the steel superstructure of the bridge complete, with road metalling and permanent way, is given as Rs. 25,18,695, and the total cost of the whole work as Rs. 48,91,151, exclusive of the railway and road approaches.

On both abutments of the Dufferin Bridge block-houses have been built, to contain troops for the military defence of the structure. Construction work on the bridge was commenced in January of the year 1881. On the 24th September 1887 the completed girder-work was tested with excellent results, by a train, consisting of two engines, each weighing 88 tons, placed in the centre, and loaded ballast wagons weighing 15 tons each, on each side, sufficient to cover one entire span of the bridge. The total weight of the testing train was 296 tons. The bridge was formally opened for traffic on the 16th December of the same year, by His Excellency the Viceroy, the Earl of Dufferin.

The accompanying illustration, from a photograph taken during construction, will give an idea of this remarkably fine example of railway-bridge engineering.

CHAPTER XI

NORTH-WESTERN SYSTEM, ATTOCK AND LANSDOWNE BRIDGES

The North-western Railway system—Outline of some of the important bridges—Detailed description of bridge over the Indus at Attock—Flood-rise of the river—Liability of the district to earthquakes—The bridge site—The design of the bridge—Getting in the foundations—Erection of the pier columns—The temporary stagings for girders—Erection of the main girders—Completion and testing of the bridge—The Lansdowne bridge over the Indus at Sukkur—Site and design of the bridge—The cantilevers—Foundation of abutments—The vertical pillars—The main inclined struts, and horizontal ties—First erection of the steel-work in England—Detailed description of the erection of the bridge at Sukkur—Temperature—Difficult setting out—Building the struts and horizontal ties—Completion of the cantilever framework—Bridging the central gap—Suspended staging employed—Completion of the work.

THE 'North-western Railway' of India is a magnificent system of 5 foot 6 inch gauge lines, situated for the most part in the Punjab, Scinde, and the frontier districts, aggregating, with numerous branches, a total length of nearly 2400 miles. The system stretches from Delhi to Lahore and Peshawur; from Lahore to Karachi, Quetta, and to the borders of Afghanistan. A considerable portion of the present North-western Railway was constructed and worked for many years by the late Scinde, Punjab, and Delhi Railway (Guaranteed) Company, which commenced operations as early as the year 1858, but the greater portion of the system has been constructed at various times by direct Government agency—in great measure as frontier military railways. In the course of their construction the railways have been carried over the whole of the great Punjab rivers—most of them, viz., the Indus, the Sutlej, the Chenab, and the Jhilum, having been bridged in two places. The size and main particulars of the chief of these structures will be found detailed in Appendix K.

Excluding the two bridges over the Indus, some of the more remarkable of these works are the 'Empress' bridge over the Sutlej at Adamwahan, consisting of sixteen spans of 250 feet each, 4210 feet in total length, with foundations carried 103 feet below low water, costing over 71 lakhs of rupees. The 'Sher Shah' bridge over the Chenab, consisting of 17 spans, of 200 feet each, 3650 feet in total length, with foundation-wells carried 75 feet below low water, costing over 28 lakhs. The 'Alexandra' bridge over the same river, consisting of 64 spans, of 133½ feet each, 9088 feet, or over 1¾ miles long, with foundations 75 feet below low water, costing over 56 lakhs. The 'Victoria' bridge over the Jhilum at Chak Nizam—opened in 1887—consisting of 17 spans of steel girders, of 150 feet each, 2720 feet long, with foundations 82 feet below low water, costing nearly 19½ lakhs. The 'Kaiser-i-Hind' bridge over the Sutlej, near Ferozepore—opened also in 1887—consisting of 27 spans, of 144½ feet each, of new pattern steel girders, carried on brick piers 26½ feet by 14½ feet, built on wells 23 feet in diameter. The bridge is 4293 feet long, with foundations 78 feet below low water, and cost over 41 lakhs of rupees. Each of these works, from the various character of the great rivers crossed, presents features of the highest engineering and general interest, but the space at command will only permit the above cursory notice.

It is necessary, however, to furnish a more detailed sketch of two very remarkable structures, either of which—as indeed will many of those omitted—compares favourably with similar erections in any part of the world. The works to which we refer are, the railway bridges over the Indus at Attock, and over a lower reach of the same river at Sukkur, the last of these bridges, as regards magnitude of clear rigid span, was for some time the largest in the world, and has since only in one instance been surpassed. The railway bridge at Attock carries a section of the North-western Railway running from Lahore to Peshawur (near the north-west frontier), and also the Grand Trunk Road, over the Indus river. This section of line was originally constructed for purely military purposes; it was completed as far as the Indus at the end of the year 1880, and beyond that river to Peshawur early in 1882, but the magni-

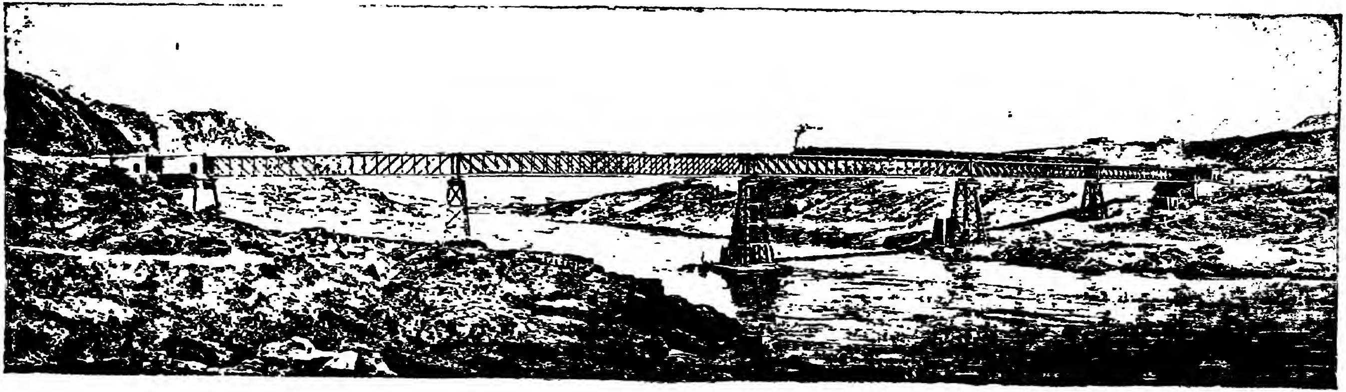
ficent bridge over the river, together with the heavy cuttings and tunnels on the approaches, were not opened until the 24th May 1883.

Above the site of the bridge at Attock the Indus drains an area estimated as equal to that of Great Britain and Ireland, viz., 120,000 square miles. Rising in the elevated regions of an unexplored portion of the Himalayan range of mountains, outside British territory, the exact length of the river is unknown, but is taken to be upwards of 900 miles. Leaving the mountain ranges about 30 miles above Attock, the river traverses a plain country in a broad shallow bed, reaching 2 miles in width; but before arriving at Attock, and for some distance south of that place, its channel is contracted by ranges of rocky hills, through which it winds in deep gorges for a distance of about 90 miles, with a cold-season water surface ranging from 300 to about 1200 feet wide. The volume of water is usually at its lowest during the winter months, from November to March, and at this time in its most contracted parts the river carries a maximum depth of water of about 30 feet. As the hot season advances, the melting of the Himalayan snows causes the water to rise an additional 20 feet or so by the end of May. The highest floods commonly occur during the monsoon months, when the rise of water at Attock reaches as much as 70-feet above low-water level. The river is also subject to exceptional floods of almost unlimited volume and rise, caused by landslips or heavy accumulations of ice, blocking the course of its mountain tributaries. Immense quantities of water impounded by the barriers thus formed are occasionally suddenly released, creating violent and unexpected floods in the main river. A flood known to have been due to temporary impounding of the water occurred in February 1858, when the water rose 70 feet at Attock, and it is probable that the great flood of 1841, said to have risen over 100 feet above low water at the same place, had a similar origin.

The Attock railway bridge presents an example of a design specially modified and adapted to meet peculiar and unusual local conditions. It was necessary to take into consideration the possible re-occurrence of abnormal floods, such as those noted above, and it was accordingly determined to place the

bottom of the girders well above the level of the great flood of 1841, or at a height of 111 feet above low water in the river at the point of crossing. The district of Attock is, moreover, liable to the contingency of earthquakes, slight shocks being of frequent occurrence, with a direction of seismic wave generally east and west. To meet this source of danger it was considered advisable to employ a more yielding and elastic material than stone or brick for the piers of the bridge, and to substitute an open wrought-iron frame-work. The wisdom of this decision was fully confirmed even during the construction of the work, for, on the 31st March 1883, a sharper earthquake shock than usual occurred, when it was found that the girders of the first span had moved forwards and backwards on the pier over one inch, and the movement was probably much greater on the higher piers in the centre of the river where it could not be measured. The expansion rollers placed under the ends of the girders permitted this degree of movement without causing any appreciable strain, but had not these been in perfect working order a considerable stress would have been thrown on the piers. In the design of the bridge, provision had also to be made for carrying the Grand Trunk Road as well as the railway. The two roads are carried at different levels, the rails above, and the cart, or military road below, between the main girders.

The site selected for the Attock bridge was at a point in the narrow gorge situated about two miles below the old Sikh Fort, which for many centuries guarded the crossing on this part of the Indus. At the bridge crossing the width of the cold-weather water surface is barely 600 feet, and the river is divided into two nearly equal channels by a central rocky shoal. Owing to the contracted section of the passage, and the consequent great velocity of the current, as well as from the prevalence of high winds which sweep through the gorge, the rocky surface of the valley within the limits of the highest floods is everwhere swept perfectly clean and bare. The channel on the east or left bank of the river carries the deepest and swiftest stream, and here the surface of the rock below water is also clean, but the right channel, having a more moderate current, has a sandy bed overlying the rock.



THE ATTOCK BRIDGE

The design finally adopted for the bridge was as follows:—The openings are five in number, the first two spans are 257 feet each in the clear, the third and fourth spans, which cross the permanent water channel of the river, are each 308 feet in clear width, and the fifth or last span, on the west side, is similar to the first and second. There are thus three spans of 257 feet and two of 308 feet, and the total length of the bridge is 1655 feet over all. The girders are carried at a height of 111 feet above the lowest water, the rails being placed at nearly 141 feet above the same level. The four piers are each formed of 8 wrought-iron columns or standards connected by horizontal and diagonal cross-bracings at intervals of 23 feet of vertical height. The four central columns form a rectangle, 19 feet by 14 feet at the top, and are only slightly inclined downwards, whilst the two up and two down stream columns, joining the main standards in the upper tier, are widely spread out so as to act as struts to prevent overturning, bearing, however, their due proportion of the load. Each column or standard is $2\frac{1}{2}$ feet square in section, and is built up of wide angle bars at the corners, joined together by $\frac{1}{2}$-inch iron plates. On two sides the plates are not continuous, but spaces are left at regular intervals, the object being to admit entrance into the interior of the columns for the purpose of riveting, and for subsequent repainting of the ironwork. On the summit level the four main columns are secured together by a cross framing of girders forming a platform on which the main girders of the bridge are carried.

The main girders, which are $26\frac{1}{4}$ feet deep, 3 feet 3 inches wide on the booms, and are spaced 18 feet apart from centre to centre, are constructed of steel, being calculated to bear a working strain of $6\frac{1}{2}$ tons on the square inch. The general aspect of the completed bridge, with surroundings, is picturesquely conveyed by the accompanying engraving, reproduced by permission from *Engineering* of November 14th, 1884. The following outline account of the methods of construction employed in the erection of the Attock Bridge is abbreviated from a descriptive article on that work, published in vol. xxxviii. of *Engineering*, Numbers dated November 28th, and December 12th and 26th, 1884.

By the adoption of 308-feet spans for the two main openings of the bridge over the permanent water-channel all difficulty with regard to the foundations of the iron piers, except in the case of one, viz. No. 3, situated on the rocky shoal in the centre of the cold-weather stream, was avoided. The surface of the rock below water at the site of the central pier, exposed to the full force of a strong current, was bare, except as regards the fine micaceous sand lodged in the crevasses or hollows. It was not practicable, therefore, to enclose the area of the foundation by means of a timber cofferdam. The foundation was consequently secured in a different manner. The outline of the space to be enclosed was irregular in plan, being determined by the form of the rocky shoal, and extended up stream considerably beyond the actual requirements of the pier. It was determined to enclose this space by sinking, and building up to water level an enclosing dam or wall, formed of bags of Portland cement concrete. To effect this in the deep water and strong current, and in the temporary absence of proper diving apparatus, barges were moored just outside the line of the proposed wall, and as much as possible of the fine sand, which in places filled the crevasses of the rock, was removed by a spoon dredge, the remainder being cleared by hand by native divers, who, however, could only work imperfectly, and for short intervals at a time, owing to the intense cold of the water in the snow-fed river. When the rock was thus cleared, small bags loosely filled with Portland cement concrete were lowered on to the rock, and rammed into the cavities, until gradually a thick enclosing wall of bags was built up to water level. Above this level a wall of rubble stone, set in hydraulic mortar, was built up to a further height of 5 feet.

The enclosed area was also divided into ten rectangular compartments by cross walls built up in the same manner, and in November 1881 pumping plant was got to work, and some of the compartments were pumped out. It was then found that the surface of the rock was not so sound as had been supposed, and that, owing to numerous fissures, the influx of water would be too great to allow of the cells, or chambers, for the shoes of the pier columns being sunk into it to the necessary depth. Proper diving apparatus having now been

obtained, it was determined to discontinue the pumping, and the compartments into which the dam had been divided were soon cleared of all sand and loose matter by the divers. The compartments were then filled in solid with cement concrete, which was left for the time necessary to harden.

Square cells were then cut down through the concrete to the surface of the rock, and were continued into the latter until perfectly sound and solid rock was met with. In cases where passages communicating with the outside river were cut into, the process had to be repeated; cement concrete being filled in, allowed to harden, and then cut through. The cells were 7 feet square, or just a little larger than the shoes of the columns. When all the 8 cells had been carried into the rock to the required depth, which in the case of the central pier was about 21 feet, the pier columns were cut to the necessary length, and the massive iron shoes were riveted on. Each bottom length was then lowered into its proper cell, and temporarily adjusted in place. The next length of the columns were fastened on, and the shoes were now brought into exact horizontal and vertical position. Fine Portland cement concrete was carefully rammed under the shoes, as well as inside and around them, and the cells were completely filled up with the same material up to the level of the top of the dam. In order to protect the standards of the central pier from the shocks of floating rafts, or other objects carried down the river, a concrete fender or cutwater, was subsequently constructed on the rock, on the up-stream side of them.

The method adopted in building up the pier columns was as follows:—A 50-foot derrick or jib was placed near the centre of the pier, capable of being inclined towards any particular column to be operated on. The 23-feet lengths of column between the horizontal and cross bracings having been previously riveted up, were hoisted into place, and the section was braced together and completely riveted. The derrick was now raised on a platform supported on the uppermost tier of bracing, and the next length was hoisted and completed, and so on, until the pier was finished to the full height. The first column shoe was set on the 6th February 1882, and the four piers were all erected and complete by the end of May of the same year.

The main girders of the bridge were built in place on platforms supported by staging erected between the piers. In the case of the three smaller spans of 237 feet, no difficulty was experienced, as the bed of the river in those spans was dry for the greater part of the year. The platforms were here carried on temporary piers spaced about 42 feet apart, formed of double columns built up of wrought-iron cylinders 3 feet in diameter, and in 9-feet lengths, with angle iron flanges; this material having been collected in considerable quantity for the purpose of constructing temporary bridges during the Afghan campaign, and in part by the use of angle iron standards, with cross struts and bracing, which happened to be available. For the two main spans of 308 feet, across the water channel of the river, a different system had to be adopted. In these spans, viz. Nos. 3 and 4, no intermediate supports were admissible, principally owing to the depth and strength of the current, and to the necessity for keeping open a clear wide channel for the heavy timber rafts and large boats laden with produce from the upper reaches of the river. The staging, therefore, in the main spans consisted of a series of long struts springing from a point near the base of each pier, and spreading out like a fan to support a horizontal beam of double whole timbers, on which the girder-erecting platform was laid. The pair of main long struts or booms on either side were spaced 19 feet apart, centre to centre, so as to come under the girders, and were braced together. All the intermediate struts forming the fan were similarly braced, and rigidly connected with each other by horizontal half-timbers, or 'ledgers,' at equal vertical distances of 12 feet; the ledgers were also secured to the main columns of the piers by heavy wrought-iron straps. The two outermost struts from opposite sides were connected above by a whole beam, 63 feet long, of sal wood, trussed with three vertical struts 10 feet deep, and by rods of 2-inch round iron, the whole forming when complete a gigantic strut and straining-beam truss, 300 feet long, and over 100 feet high.

These massive stagings proved exceedingly satisfactory, the maximum deflection or sinking under the enormous load of over 600 tons imposed upon them—in addition to their own weight—being only 1⅛ inch. They proved, however, to be by

far the most difficult, as well as the most tedious, part of the whole bridge operations. The stagings were commenced in October 1882, and the second one was not completed until the beginning of February 1883; the work of erection having been much delayed by storms and high winds, which are very prevalent at Attock, during which it was unsafe to allow men to work in such a high and exposed situation, and where their limbs would quickly become numbed by the cold.

The erection of the girder work was effected by the use of gantry cranes moving on rails laid on beams outside the girders. In the case of the first of the 308-feet spans, from the laying in place of the bearings, until the top booms were closed in, eleven days were occupied, and in the case of the second span ten days sufficed for the same work. The complete riveting took about a week longer in each case, and on the 5th May 1883 the first locomotive passed over the bridge.

The structure a few days afterwards was officially tested with a test train, consisting of three locomotives weighing 64 tons each, and eight loaded wagons of a gross weight of 18 tons each, the engines being placed in the centre of the train. The Government of India rules for testing railway bridges are, that the load shall be allowed to stand on each span from ten to fifteen minutes; the testing train is then moved first slowly across the span, and lastly the train is driven across at the highest speed. In each case the deflections are carefully observed, as well as the lateral oscillation under the high-speed test. The result of the trials in each case at the Attock Bridge was very satisfactory, and the bridge was at once opened for public traffic. The total cost of the Attock Bridge is officially given as Rs. 32,20,516, but it is not stated whether this excludes the block-house defences which have been constructed for the military fortification and protection of the bridge.

The section of the North-Western Railway, extending from Lahore, *viâ* Mooltan to Karachi, crosses the Indus at a point close to the town of Sukkur. For many years a break here occurred on the railway, and the passage was effected by a ferry. Subsequently landing-stages, with steamers and flats, were provided, by means of which the railway vehicles were transported across the river; but soon after the year 1880 active

steps were taken for the elaboration and provision of a permanent high-level bridge, to render secure this important link in the chain of communication between upper India and the coast. At Sukkur the Indus passes through an isolated ridge of nummulitic limestone of small elevation, and the river is unequally divided into two channels by the island of Bukkur. The left or Rohri channel carries the main body of water, which is here 70 feet deep at low water. The rise of the river in times of highest floods is 17 feet, and the velocity of the current is about nine miles an hour.

It was found practicable to bridge the right or Sukkur channel by three girder spans of 278, 238, and 94½ feet respectively, the erection of which presented no difficulty, but the main or Rohri channel—owing to the great cost, and undesirableness on many grounds of employing a central pier—could only be crossed by a single span of exceptionally large dimensions. Hard limestone rock, sloping steeply down to the water, is found on the left bank and on Bukkur island. At the upper part of the island the channel could have been crossed by a single span of 650 feet, but the approach embankment would have cut through the middle of the town of Rohri, and its increased cost, together with the heavy compensation that would have to be paid for land and property, annulled the advantage of this alignment. It was therefore determined to cross the channel somewhat lower down, at a site where the width of the single span could not be reduced below 820 feet, or 790 feet in clear width from face to face of the masonry abutments on either side. The structural features of the design adopted for spanning this exceptionally large opening have been much criticised, chiefly on account of the special difficulties of erection of the ironwork which were entailed.

The 'Lansdowne Bridge'—so named after the then Viceroy and Governor-General of India—consists of single cantilevers, one on each side of the channel, each having a projection or overhang of 310 feet. The central gap, 200 feet long, between the projecting ends of these cantilevers, is spanned by independent girders. The general features of the design and aspect of the huge main opening of the bridge—the superstructure of which is throughout constructed of steel

—will be best understood from the illustration (*vide* Frontispiece). Each cantilever virtually consists of a gigantic shear legs, or guyed crane, used to support the bridge platform at a height of 52 feet above low water, or 35 feet above maximum floods. The foundation-work consisted only in clearing away the material down to the rock on either bank, which was benched to receive the abutment masonry. In the absence of suitable stone this was constructed of Portland cement concrete. The anchorings for the back stays or guys, which are cellular structures 32 feet by 12 feet by 6 feet—weighing 35 tons—are situated about 250 feet to the rear of the abutments, and about 50 feet below rail level, and they are bedded firmly into or behind the solid rock in cement concrete. On the abutments the main bed-plates for the support of the cantilevers are also cellular, 20 feet long by 10 feet by 8 feet—weighing 55 tons. They are secured to the abutments by fourteen holding-down bolts, 9 feet long and 3 inches in diameter, and further, to provide against any backward thrust, they are connected with the solid rock behind them by a filling of Portland cement concrete. The pillars and struts of the main framework of the cantilevers are longitudinally spindle-shaped, square in section, and are built up of curved corner-plates stiffened by angle bars at the edges, and tied together by horizontal and diagonal braces forming an open framework. The first vertical pillars, carried on the abutments somewhat in the form of the letter A, are placed with feet 100 feet apart, the legs are 170 feet high, and weigh 183 tons. The main inclined struts similarly disposed, forming the 'jib' of the crane, are 230 feet long, and weigh no less than 240 tons. These members are joined together at the top by a horizontal tie-girder 123 feet long, and weighing 86 tons; the three members constituting the enormous primary triangle of the cantilever framing. The entire steel work of each cantilever was made in England, and was first put together in the maker's yard, with the aid of a timber scaffold (such as could not, however, be used at the site of the bridge), before shipment, and the huge erection for a long time formed a most conspicuous object on the banks of the lower Thames. Apart from its great size, the chief interest of the Lansdowne Bridge over the Indus lies in the difficulties encountered in its erection,

difficulties which were successfully overcome by many ingenious expedients. It would not be possible, without the aid of numerous diagrams, and the introduction of too many technicalities to be readily understood by the unprofessional reader, to enter into any full and detailed explanation of the erection of this remarkable work. The following brief account—the data for which has been principally derived from a paper descriptive of its erection read before the Institution of Civil Engineers on the 2d January 1890—will convey a general idea of the methods employed.

The first members to be erected were the large vertical pillars on the abutments. These in actual construction were built up with a slight backward rake—or inclination of 6 inches to allow for the requisite elevation—or 'camber' at the end or nose of the cantilever, and it was, therefore, necessary first to erect a timber scaffold to support them during construction. The scaffold was built to the profile of the holding-back guys, and served also to erect them. The pillars were built up from the bed-plates, and the guys from the anchorings, until they met at the top, and the junction had to be made so as to give the backward rake of 6 inches to the pillars at a temperature of 100°, which was fixed upon as the normal temperature, for at Sukkur the temperature in the sun runs up to 180°, and often exceeds 90° during the night. The next member of the cantilever framework to be erected was the huge primary strut. These immense booms, 230 feet long, and weighing together 240 tons, supported on a small base and riveted to the bed-plate, had to be built out with a rake or inclination in two directions, and their construction consequently involved a very difficult piece of setting out to preserve them in proper alignment and direction. A temporary staging was erected on the first lengths of the roadway girders, which it had been possible to place in position by supporting their outward ends on a temporary pier built in the river just outside the abutment. On this staging was placed a double derrick crane, with a sufficient sweep to command a considerable section of the length of the main strut. A piece of the strut—generally about 30 feet long and weighing 5 tons—was lifted out into its place, and held by $1\frac{1}{2}$ inch wire rope; its proper position

was adjusted with great and careful accuracy, the various connections were made, and the work was then riveted up. After the strut had been thus built out beyond the reach of the derrick, another one, 75 feet long, was erected at a higher level, on one of the cross or 'distance' girders, and the building out continued; the work being held back by strong back ties secured to the vertical pillars, and by a special main tie from the summit of the latter.

On the completion of the enormous struts to full length and height, it was found that the exact span for the upper horizontal tie was in error to the extent of only $\frac{5}{8}$ inch on one side of the river, and $1\frac{1}{4}$ inch on the other. The next operation was the erection of the permanent horizontal tie itself, connecting the head of the vertical pillars with that of the struts. The weight and length of the horizontal tie was too great to admit of its being lifted in one piece; it was, therefore, decided to erect it on a temporary suspension bridge, or suspended staging, carried between the heads of the two main members. The suspension cables, however, being attached to the strut at the outer end, the operation presented this difficulty—that the horizontal pull of the ropes when loaded was more than sufficient to counterbalance the weight of the strut by about 20 tons. This difficulty was met by loading the nose of the strut to the requisite extent to counterbalance the increasing horizontal pull of the temporary bridge as the load came on it, the main tie being first slackened. On the suspension cables, braced trestles were arranged, so as to support the steel work of the horizontal tie during its construction, and until the head of the main verticals and the huge inclined struts were permanently joined together, thus completing the first triangle of the cantilever framework.

As soon as this triangle was successfully framed on each side of the channel, two firm permanent points of support were available from which to hang a system of overhead suspenders, or carrying cables, from one to the other, extending for a distance of 547 feet across the channel, and by the aid of these suspender cables, and an ingenious arrangement of tackle and gear, worked from the horizontal ties by portable engines placed below, the remaining less heavy portion of the canti-

lever steel work was built out over the river, the work being assisted by two barges of 400 tons burden (provided with suitable carrying trestles), whenever the current permitted them to work.

On the completion of the two cantilevers projected from either abutment, it was found that their ends or noses were exactly level, and in correct line—or rather in the middle position of the diurnal variation caused by the alternations of temperature, for, as the bridge lies north and south, the effect of the sun acting on alternate sides of the steel work caused the nose to oscillate nearly an inch either way. The width of the central gap was also correct at mean temperature. The only work now remaining was the erection of the central and independent girder span, 200 feet in length, joining the noses of the cantilevers, and completing the connection across the river. The gap is spanned by a pair of ordinary girders resting on rollers placed at the ends of the cantilevers. In designing the structure it was supposed that these girders could be floated into position, but this was not, for various reasons, found practicable. It was then proposed that they should be built on the cantilevers and launched across the opening, but it was finally decided to use a staging built out from the cantilever noses, so as to enable the girders to be erected in place. The temporary stage employed—as it was not possible to provide any central support from the river-bed—was a deck bowstring bridge 196 feet 8 inches in clear span, and weighing 56 tons complete without the floor-planking. The line of links forming the bottom chord was drawn across the gap by the overhead tackle, and on the link pins the stumps of the verticals and diagonals were strung. Next a length of the top chord, with the verticals and diagonals hanging loose, was sent out by the overhead tackle and placed in position, each vertical being dropped over the stump belonging to it, the joints being made by the use of cottered or slotted pins with keys. This operation was repeated until the temporary bow girder was completed, each bay being successively secured by the cross-bracing. On the completion of the top chord the holding-back chains were slackened off, and the previously suspended structure became a stiff girder; the pair of girders were then

horizontally braced to each other. This temporary work was completed, with some difficulty, in seven days. The permanent girders were erected on sand boxes, sufficient camber, or rise in the centre, being given in setting the lower booms, to allow for the deflection of the bowstring staging girders. The pieces were all run out by the useful overhead gear, and the work of erection was practically completed in four and a half days.

The floor of the Lansdowne Bridge is formed of corrugated deck plating filled with wood, so as to give a cartway on the same level as the railway, which passes over the bridge by a single line. A footway for men and beasts of burden is also corbelled out on both sides. Work on this truly noble bridge was begun on the anchors of the Bukkur cantilever in April 1887, but at first progressed slowly for want of the steel work. From November 1887 the work of erection was rapidly pushed forward until its completion and testing in March 1889. The total weight of steelwork in the huge main span is 3316 tons. The total cost of the Lansdowne Bridge, including the three minor spans over the Sukkur channel, is given as Rs.33,46,720, of which Rs.27,89,340 is the cost of the great cantilever span over the Rohri channel.

CHAPTER XII

NORTH-WESTERN SYSTEM—KHOJAK TUNNEL—OTHER RAILWAYS

The Sind-Pishin section of the 'North-Western Railway'—Outline of system—The new Quetta loop by the Mushkaf and Bolan valleys—Rapid construction of the line from Ruk to Sibi—Hurnai Valley line—Extension of the railway from Bostan to Chaman—The Khojak Tunnel—Largest railway tunnel in India—Descriptive details of construction—Progress of the shafts and headings—The rope inclines—Completion of the tunnel—Extraordinary effects of an Earthquake—General particulars of the North-Western system of railways—Outline of other railways—The Bombay Baroda and Central India—The Tapti and Nerbudda Viaducts—The Rajputana-Malwa State Railway of metre gauge—Principal structures and works—The Bengal, Nagpur, and Indian Midland Railways—Principal works—The Railway water-supply at Jhansi—East Coast Railway—The Bezvada bridge—Railways in Burma.

At Ruk Junction, situated only a few miles beyond the point where the Lahore and Karachi trunk section of the North-Western Railway crosses the Indus by the Lansdowne Bridge, the Sind-Pishin section of the same railway commences. The main line of the latter, $335\frac{1}{4}$ miles long, has been constructed as a frontier military line, and may be divided into two portions. The first or level desert length of $133\frac{1}{4}$ miles, runs from Ruk Junction to Sibi, situated near the foot of the Beluchistan Mountains, and the mouth of the Bolan and Hurnai valleys. The second or mountain railway length extends from near Sibi, *viâ* the Hurnai valley, to Bostan (situated a few miles north of the frontier military station of Quetta) and thence proceeds *viâ* Kila Abdulla and the Khojak Pass and tunnel to New Chaman, on the northern or Afghanistan side of the dividing Amran range of mountains, within a distance of 70 miles of Kandahar.

A loop line extending from Sibi, *viâ* the Bolan Pass to Quetta and on to Bostan, was originally constructed, but the portion of this loop, 98½ miles long, passing through a very difficult line of country from Sibi to Quetta, was made under great stress as a temporary military line, and after having been maintained in the face of great difficulties for some years was in November 1891 made over for reconstruction on a new alignment. The new Quetta loop by the Mushkaf and Bolan valleys is not yet open, but work on it is being rapidly pushed forward, as it is of the highest importance that a second alternative line of railway should be permanently maintained between Sibi Quetta and Bostan, in case the main line by the Hurnai valley should at any time be blocked by landslips or other accidents; always liable to occur on a severe mountain railway. On the Mushkaf alignment of the Quetta loop, the works are generally of a very heavy character. There is one tunnel of more than usual importance, viz., that being driven through the line of hill forming the watershed between the Mushkaf and Bolan valleys known as the 'Panir.' This tunnel will be about 3000 feet in length. The line—which will be about 86 miles long—runs along portions of the old Quetta loop from Bolan Junction to Nari Bank—4 miles, and from Kolpur to Quetta—25 miles. The new portion from Nari Bank to Kolpur is, therefore, about 57 miles in length. The total rise from Sibi to Kolpur is 5463 feet, and the railway gradients over intermediate lengths are, 1 in 55, 1 in 35, 1 in 33, and 1 in 25. From the mouth of the Mushkaf valley the country is very difficult, involving eight tunnels and four crossings of the Mushkaf river. In the Bolan valley there will be three tunnels, and some exceptionally high embankments and deep cuttings. On approaching Kolpur the works are again exceedingly heavy, including numerous rock-cuttings, three tunnels and large bridges for nine crossings of the Bolan river at high levels above its bed. Information as to the details of these works is at present very scanty.

Turning now to the main line, and to the first portion of the Sind-Pishin section from Ruk Junction to Sibi. At the end of the year 1879 it was determined to push forward—for emergent military purposes—and with the greatest possible

rapidity, a line of railway communication from the Indus valley to the Bolan Pass, this being the best available route leading from British India into Afghanistan. *Only four months from the date of receiving the first order, a broad-gauge railway,* $133\frac{1}{4}$ miles long, was opened *for military traffic from Ruk to* Sibi. The greater portion of this length of line traverses a triangular-shaped waterless plain, dry, barren and treeless, locally named the 'Put' or desert. This sandy plain slopes at an average gradient of 1 in 2000 from the foot of the Beluchistan Mountains towards the Indus valley. For the first forty miles, however, from Ruk, the ground slightly falls away from the elevated channel of the Indus, and the railway over this length is carried through thick jungle, except near the towns of Shikarpur and Jacobabad, crossing in its course several large inundation canals and water-distributing channels.

The rapidity with which the materials for the Ruk Sibi section of the Sind-Pishin Railway were collected, and the line laid and made serviceable for locomotive traffic, has hardly ever been surpassed. Although the work in itself was of the simplest character, its prosecution was attended with exceptional difficulties in connection with the housing, feeding, and watering the large working parties of men and animals whilst crossing the terrible desert portion of 93 miles, as well as from the character of the climate during the winter months, which is hot by day and intensely cold by night. The supply of water was based on the estimated requirement of 5000 men at two gallons per day, and 2000 beasts at five gallons, equal to a daily supply of 20,000 gallons, and the supply was furnished by training out water tanks by the material trains running to the 'tip,' or advanced head of the works. The execution of $133\frac{1}{2}$ miles of railway in 101 days, or at an average progress of $1\frac{1}{3}$ miles per day is a feat worthy of mention, and was only possible under the most perfect system of organisation in every detail of the operations. Yet so ably conceived were all the arrangements for the regular and orderly supply, whether of railway material, or of food, water, fuel and shelter for the labourers and staff, during the fifty working days occupied in carrying the railway over the ninety-three miles of inhospitable desert, that practically no special inconvenience

was experienced, and from first to last the work progressed with the utmost regularity and mechanical precision.

From near Sibi—the end of the desert section—the main line traverses, *viâ* the Hurnai valley, a very difficult mountainous country, involving works of exceptionally heavy character. The line throughout has been constructed for a single line as far as Gulistan (situated a short distance beyond Bostan), beyond which it is double. The length of the line from Sibi, *viâ* Hurnai and Bostan, to New Chaman, the present terminus of the railway, is 202¼ miles: of this length the Sibi-Bostan portion was opened in the the year 1887. The ruling gradients on this portion vary between 1 in 45 and 1 in 76, with 1 in 200 between Sibi and Nari. Between Bostan and Gulistan the ruling gradient is 1 in 100, and from Gulistan to Chaman, 37½ miles in length, the ruling gradient reaches 1 in 40, with curves of a minimum radius of 819 feet. Over a length of 67 miles the bridging, tunnelling and earthworks on the Hurnai valley section of the railway are of exceptional, and in many cases of an extraordinary description. The more important tunnels are nine in number, the two longest being 2024 and 1233 feet respectively. The total length of these tunnels is 8402 feet or 1·6 miles, and their construction cost the sum of Rs.2,36,231. At 316 miles from Ruk Junction on the extension of the railway from Bostan to Chaman, the great Khojak tunnel pierces the Khwaja Amran range of hills, the approaches to which on either side involve earthworks of a most formidable character. The Khojak tunnel—the largest railway or other tunnel in India, has a total length of 12,870 feet, or just under 2½ miles. Of this, 7870 feet are ¾ lined with masonry, and the remaining 5000 feet is ½ lined. It has been completed with a section wide enough to carry through the hill a double line of the standard or 5 foot 6 inches gauge, at a total cost of Rs. 65,24,372. Very little information is available as to the methods and details of construction of this recent and interesting work, which was commenced in April of the year 1888: was practically completed in September 1891, and was formally opened for traffic on the 1st January 1892. The work on the tunnel was aided throughout by a special staff of European miners, tunnellers, and electricians.

CHUPAR RIFT, HURNAI VALLEY RAILWAY.

The orders of Government for the extension of the Sind-Pishin Railway from Kila Abdulla (10 miles beyond Gulistan) through the Khwaja Amran range, were issued at the end of 1887, but owing to the severity of the winter in these high regions nothing could be immediately effected at the main tunnel, or for the rope inclines over the summit of the pass, which it was decided to construct for temporary purposes, and for use during the construction of the main work. Staff quarters and workmen's shelters were, however, got ready; the excavation of the deep cutting at the eastern approach to the tunnel was commenced, as well as the east and west lined shafts. Small shafts were also sunk at each main entrance down to the tunnel level. In the course of the following year, viz. 1888-89, the heading from the east portal of the tunnel was run out to meet the east cutting, and towards the west was carried 2296 feet into the hill. The second lined shaft was pushed down to the full depth of 318 feet, and the headings were carried 932 feet eastwards towards No. 1 shaft, and 1249 feet westwards towards No. 3 shaft. During the summer months the springs failed, and water for all the working parties on the east side of the hill had to be brought up in tanks from Kila Abdulla, a distance of ten miles. The work at No. 3 lined shaft was sunk to the full depth of 281 feet, and the east heading from it was carried 2740 feet towards No. 2. In this shaft, on the 2d March 1889, a large spring was tapped. Before any steps could be taken the pumps were 8 feet under water, and by the 13th the water had risen 156 feet in the shaft, necessitating vigorous measures to keep down the influx.

The gallery from the west portal was driven for a distance of 2000 feet eastwards; here also the heading was exceedingly wet, but being on an ascending grade the backward drainage was easy. This length of tunnel was joined to the heading from No. 3 shaft on the 28th April 1889. At the end of the official year, 1888-89, the length of headings driven was 7373 feet, out of the total length of 12,870 feet, 607 feet of the masonry lining for double line was also executed, and the rails (also for double line) were completed from Kila Abdulla on the permanent formation. A temporary railway about seven miles long was laid up to the foot of the rope inclines, Nos. 1

and 2 of which were got to work over the Khojak summit in October 1888, and No. 3 in February 1889. These inclines served the purpose of conveying over the ridge, fuel and all materials required for the west tunnel works and for the railway beyond. Sixteen miles of permanent way material was thus conveyed over the hill. The site for the New Chaman Station or terminus of the line, was also selected at a spot about six miles below Chaman Fort, at the foot of the western slope of the Khwaja Amran range.

During the year 1889-90 the headings from the shafts, which throughout were driven in water-bearing shales or shingle with layers of soft mud, requiring heavy timbering, were pierced so as to practically complete this operation, the progress during the year being 5070 feet. The masonry arching was also completed for a length of 5997 feet. The headings of the tunnel were joined towards the end of April 1890. Owing to the large quantity of water met with, and also to the extremely treacherous nature of the ground in the final 300 feet of the workings, which caused frequent slips and entailed the most careful timbering, the progress of the headings was very seriously delayed during the last few months. The progress of the arching was also very greatly affected by the same cause.

By September of the year 1891 the masonry lining was virtually completed, and the first construction train passed through the tunnel from end to end on the 5th of that month. On the 1st January 1892 the section of line from Kila Abdulla to New Chaman station, 29·35 miles in length, laid with a double track, and passing through the Khojak tunnel, was formally opened for traffic; the works throughout this difficult section of line having occupied nearly four years in all.

To convey an idea of the vicissitudes and dangers to which some Indian railways are exposed, the following press notice of the extraordinary effects of an earthquake, which occurred on December 20th, 1892, in the Quetta district and southern parts of Afghanistan, will be of interest:—'In the neighbourhood of the Khwaja Amran range the shock was very severe: a tower in one of the blockhouses was cracked, some walls were shattered, chimneys were shaken down, and several old houses

MOUTH OF KHOJAK TUNNEL

tumbled into ruins. In the Khojak tunnel the noise was deafening, and workmen engaged on the roofing were thrown from their perches to the ground. There was, however, nothing very extraordinary in these effects; it was on the line of railway between the tunnel and Old Chaman that a curious phenomenon occurred. At mile 643 (from Karachi) four or five lengths of rail were found to have been bent by being opened out sideways, while all the joints near by were jammed up tightly. The bent rails were removed, and the work of putting in new ones was proceeded with. What was the surprise of the engineers to discover that the measure was less by 2 feet 6 inches than the original length. This was due to a crack or 'sheer' which crossed the railway bank at an angle of about 18 degrees, exactly at the place where the track had been contracted. This crack bears a little east of the meridian, passes through the old bazaar near Chaman Fort, and according to native reports, extends across the main range of the Khwaja Amran eighteen miles away. The fact clearly established by the shortening of the railway track (says the *Pioneer*) is that the earth's crust has contracted 2½ feet in the vicinity of the Khojak. This will be good news for those scientists who are on the watch for facts to support the theory of the gradual contraction of the earth. The evidence is indisputable, and the photographs taken on the spot show exactly how the rails were twisted out of the straight. One rather shrinks from thinking what the effect on the Khojak tunnel would have been had it come within the destructive action of the shock.'

The total length of the whole North-western system of State railways at the end of the year 1891 was 2399½ miles, including 98½ miles temporarily made over to the Mushkaf Bolan Railway, and 11 miles constructed, but not working. The system is administered entirely by the State, and includes a considerable mileage of non-commercial frontier railways constructed and maintained as a portion of the military defence of the empire. The kind and weight of the permanent way over such an extensive system of lines varies considerably, but 68 lbs. double-headed steel rails, and 75 lbs. flat-footed steel rails are the most commonly used for renewals, laid on sleepers of cast-iron, wrought iron, or wood in different situations.

The total capital outlay on the whole North-western system of railways, exclusive of steam ferries and suspense items, is given as Rs. 3333,46,055, or 38⅓ millions sterling at par of exchange, or an average rate of Rs. 1,59,757 per mile of road.

An early and important trunk line of railway on the standard gauge is that belonging to the 'Bombay Baroda, and Central India Railway Company.' This railway, 460¾ miles long including branches, with 60 miles of double track, extends from the Bombay terminus at Colaba to Ahmedabad, and effects a junction with the Rajputana-Malwa State Railway of metre gauge, extending thence to Agra and Delhi. The latter railway has been leased to the Company from the 1st January 1885 to the 30th June 1900. Some portions of the Bombay Baroda, and Central India Railway were opened as early as the year 1860, and the system has since gradually expanded to its present dimensions. The line runs northwards from Bombay *viâ* Surat in close vicinity to the coast, in accordance with the system of coast lines originally advocated by Colonel Kennedy, to which reference has been made in a previous chapter. The principal engineering works on the railway, which, however, contains many of considerable secondary importance, are the viaducts over the Nerbudda and Tapti rivers.

The bridge originally constructed over the Nerbudda was seriously injured by a flood in the year 1876. The structure was repaired and maintained for some little time, but was eventually replaced by an entirely new viaduct, which was opened in 1881. The new viaduct is constructed with piers for a double road, and consists of twenty-five spans of 183½ feet, each carried at a height of 48½ feet above low water, and with foundations 76 feet below the same point. The total length of the work is 4687½ feet, and it was completed at a cost of Rs. 37,75,759. The Tapti viaduct is a smaller structure, having thirty spans of 60 feet each, carried at 50½ feet above low water. The greater portion of the permanent way on the Bombay Baroda, and Central India Railway system is laid with double-headed rails weighing 68 and 69 lbs. per yard, on timber sleepers, iron sleepers being, however, used for renewals. The earthworks are generally for a single line, but the piers and abutments of bridges are made to carry a double track.

The Rajputana-Malwa State Railway—which is a metre *gauge system of lines, aggregating, with branches, 1674 miles in length—represents the first and only important trunk system constructed on that gauge in India. The main line* extends from Ahmedabad, *viâ* Ajmere and Jeypore, to Delhi and Agra, and has numerous important branches, or connected narrow-gauge lines. The first section opened for traffic was from the Delhi end in the year 1873. The line is constructed for a single track. Sufficient land, however, is occupied to admit of another line of rails being laid. The rails originally used were 36 lbs. and 40 lbs. weight per yard, laid on wooden cross sleepers. The 36 lb. iron rails have nearly all been replaced by steel rails, weighing 41¼ lbs., and steel rails of 50 lbs. section are now used for renewals on certain lengths.

The principal structures on the Rajputana-Malwa State railway are the bridges over the Nerbudda, and over the Jumna at Agra and Muttra. Important bridges also occur over the Bangunga, Shallas, Dhund, Amanishah and Sipra rivers—the latter consisting of six spans of 150-feet girders, on masonry piers, and there are heavy works on the ascent of the Vindhya range of hills, and on that of the Aravalli range west of Ajmere. The viaduct over the Nerbudda is a fine structure, consisting of fourteen spans of 183 feet, carried at a height of 80 feet above low water, costing Rs. 18,73,925. The bridge over the Jumna at Agra has sixteen spans of 133 feet each, with foundation of piers 70 feet deep, and that over the same river at Muttra has seven spans of 150 feet, with pier foundations sunk 71 feet below low water. The cost of these Jumna bridges was Rs. 18,33,877 and Rs. 8,49,000 respectively.

The two most recently finished standard-gauge trunk-lines now open for traffic in India are the Bengal-Nagpur, and the Indian Midland railways, both constructed by companies. The Bengal-Nagpur main line extends from Asanol (132 miles west of Calcutta on the East Indian Chord line) to Nagpur, the chief city of the Central Provinces, where it connects with the Great Indian Peninsula Railway from Bombay. It consequently completes an important direct communication, 1278½ miles in total length, between the two capital cities of India, viz. Bombay and Calcutta. The main line of the Bengal-Nagpur

railway is 627 miles long, and including the Umaria-Katni State line, taken over by the company in 1888, the system has a total mileage of 860¾ miles. From the Nagpur end the first 145½ miles of the line was originally constructed as a provincial State railway on the metre gauge. This length was, however, converted to the standard gauge, when the extension of the line to join the East Indian railway near Calcutta was undertaken by a company. The converted length from Nagpur to Raj Nandgaon was opened in November 1888, and the new trunk system, which was opened in sections, was completed, including nearly all its branches, early in 1891.

On the main line the permanent way consists of 75 lbs. flat-footed steel rails laid on transverse steel sleepers. There is a good deal of heavy bridge-work on the railway, the two largest structures being that over the Sheonath, consisting of fourteen girder spans of 150 feet each, and over the Damuda, of two spans of 100 feet, and ten of 200 feet each. Two important tunnels also occur on the system, viz. the Saranda tunnel, 1641 feet long, through rock and rocky shale, costing over 7½ lakhs of rupees,[1] and the Bhortonck tunnel, 1000 feet long, through hard rock interspersed with veins of quartz, costing over 2 lakhs of rupees.

The Indian Midland Railway is an important system, comprising 677¼ miles of standard-gauge lines, the main trunk of which, 315½ miles in length, extends from Bhopal (where it is in communication with Bombay by the Bhopal-Itarsi, and Great Indian Peninsula railways), *viâ* Jhansi, to Agra. A branch, 180¼ miles in length, extends eastwards from Jhansi to Manikpur, on the Jubbulpore branch of the East Indian Railway. From Jhansi also another branch, 135¼ miles long, extends northwards to Cawnpore, and a short branch of 46¼ miles runs from Bina to Saugor. The Bhopal-Itarsi State line, of 57 miles, is worked by the company, and the system—which was virtually completed by the end of the year 1889—embraces several projects, initiated and partly or entirely constructed, by the State, the whole being taken over and worked under contract by the Indian Midland Railway Company.

[1] The work is not quite finished (1893).

The main line and branches of this railway are constructed for a single line, with flat-footed steel rails weighing 80 lbs. to the yard, laid on oval pot sleepers weighing 80 lbs. each (except on the length from Cawnpore to the Jumna near Kalpi—where the rails are of 75 lbs. section). There is a large amount of bridge-work of an important and costly character. The bridge over the Chambul river (opened only in May 1891) consists of twelve spans of 186, and two of 136 feet, carried at the great height of 112½ feet above low water, with pier foundations 75 feet below the same point. The cost of this work was 32,71,035 Rs. The bridge over the Jumna at Kalpi (constructed by the State) consists of ten spans of 250 feet each, placed 76½ feet above low water, with pier foundations sunk 90 feet, and cost Rs. 25,27,545. There are two bridges across the Betwa river: one (Manikpur) opened in 1889, has thirteen spans of 150 feet, with one of 60 feet, carried at 77¾ feet over the lowest water—the other (Laltipur) has nine spans of 150 feet. These bridges cost Rs. 13,95,181 and Rs. 7,64,672 respectively. The bridge over the Ken (Banda) has twelve spans of 100 feet each, and one of 250 feet, carried at 66 feet above low water, and cost Rs. 7,36,008. Besides these bridges there are numerous others of considerable size. Between Jhansi and Gwalior some heavy rock-cuttings over the Antri pass, with a bridge of nine spans of 100 feet, and one of 60 feet, over the Sindh river. On the Bina-Saugor branch the ruling gradient is 1 in 100. On the main line the ruling gradients are 1 in 200, and 1 in 150, and from Jhansi to Manikpur 1 in 125.

The principal centre of the Indian Midland Railway is situated at Jhansi, from which place four separate lines of rail radiate in different directions. The large railway staff of all departments here collected forms a very considerable civil population, and in order to provide water, both for the railway locomotives and works, and for the staff of employés, some extensive water-supply arrangements became necessary. The yearly rainfall in the Jhansi district is comparatively low and fluctuating, and it was considered advisable to provide a sufficient storage of water to meet all the demands of the railway during several years of deficient rainfall. For this purpose a storage reservoir, covering 150 acres of ground, and containing

400 million gallons of water, has been constructed near the village of Guddia, situated about 4 miles west of Jhansi station, by throwing a weir across the Pahooj river, where it passes through a gap in the granite hills, and it is calculated that this reservoir will be sufficient to meet all the demands of the railway during a period of three successive years of minimum rainfall. The reservoir depends for its supply on a catchment basin of 84 square miles; and 4 inches of rainfall on this,—allowing for absorption, etc.—is estimated to be sufficient to fill the reservoir.

The main weir, which is 620 feet long, and 34 feet high, above the bed of the river, is founded on solid rock, and is built of masonry throughout. It has been made of sufficient section to allow for its future raising if necessary. At the north end the weir abuts on the rocky base of the hill. At the south end it terminates in a substantial abutment, raised well above the highest water-level, on which the boilers and pumping machinery are placed. In continuation of the main weir, behind the abutment, and connecting it with the face of the hill which bounds the reservoir on the south, is a massive bund or embankment, 750 feet long, on which the delivery main is carried. This bund is constructed of earthwork. Three hundred feet down stream is a secondary dam, designed to head up the water and form a cushion for the overflow of water from the main weir. The pumping machinery is calculated to deliver 24,000 gallons of water per hour, direct through 4 miles of 9-inch main, to a height of 87 feet, into a high service reservoir constructed at Jhansi, from which the distribution takes place by gravitation. This system of railway water supply has been constructed at a cost of 2,92,000 Rs.—or £29,200 at par of exchange.

On the 17th March of the current year (1893) a large railway bridge on the new 'East Coast Railway,' now in course of construction, was opened for traffic. This important bridge—which crosses the river Kistna at Bezvada, and is the largest in Madras, has occupied three years in construction. It consists of twelve girder spans of 300 feet each, carried on piers of stone masonry. The East Coast Railway of standard gauge, will, when entirely completed, connect Madras with Calcutta,

and will considerably shorten the journey between the two cities. The portion of it at present under construction has a length, with branches, of 516 miles.

No allusion has been made in this volume to the lines of railway constructed in Burma; these being outside the limits of India. In concluding the present chapter, however, it may be of interest to give a few particulars regarding the railways in that province. The Burma railways are all of the metre gauge, and emanate from the port of Rangoon. The 'Irrawadi Line,' 161 miles long, extends from Rangoon to Prome, and is laid with steel rails of 50 lbs. section for a distance of 29½ (9 miles of which are double), and beyond with rails of 40 lbs. to the yard. The bridging is heavy, owing to severe floods from the Irrawadi river. The 'Sittang Line' runs 166 miles from Rangoon to Toungoo, and is laid for a single track, with steel rails of 41¼ lbs. section on wooden sleepers. The bridging is especially heavy, there being 15,730 lineal feet of waterway, or an average of over 94 feet per mile of line. From Toungoo the 'Mandalay Line' extends 220 miles to the latter city, and is laid with steel flat-footed rails of 50 lbs. to the yard. There are seven important bridges on this length, each with three or four spans of 100 to 150 feet. The 'Mu Valley Railway' has been carried for 53 miles north of Mandalay, and is in course of construction for a further 261½ miles to Mogaung.

The total mileage of railways open for traffic in Burma, including branches, at the end of March 1892, amounted to 630 miles. The Irrawadi line to Prome was opened in the year 1877. The Sittang line to Toungoo in 1884-85; and the extension to Mandalay was completed in the year 1889.

CHAPTER XIII

GENERAL WORKING RESULTS AND STATISTICS—CONCLUSION

Mileage—Capital cost, and working results of Indian railways—Value and exactitude of Indian railway statistical returns—Growth of the Indian railway system—The standard gauge—First departure from it—Introduction of the metre gauge—Principally confined to feeders—Special gauges—Change of policy—Assisted companies—Mileage and respective gauges of Indian railways by quinquennial periods—Classification and mileage—Capital outlay and cost per mile—Reasons of difference in mileage cost of standard and metre gauge lines—Working results—Gross earnings—Working expenses—Percentage of working expenses to gross earnings—Net earnings—Return on the whole capital expenditure—Passengers and goods traffic—Main results—Classes of vehicles—Rates and fares—Early introduction of two classes only—Passenger and goods rolling-stock—Distribution of persons employed—Native engine-drivers and shunters—Accident returns—Fuel supply—Consumption of fuel—Indian coal—Centralised administration and control of Indian railways—Advantage to India—Imperfect powers of the Board of Trade in England—Concluding remarks.

It is now time to convey as briefly as possible to the reader, a general idea of the whole extent of the Indian railway system, and by the assistance of such statistical details as may be of general interest, to indicate some of the principal data respecting the mileage, capital cost, and working results of Indian railways, considered as a whole, and to note their exceeding value and importance to the Government and peoples of India. In doing this, it will be unavoidably necessary to make use, to a certain extent, of figures, and tabular statements, expressive of quantities and values, for which the indulgence of the reader is craved.

It would, as a preliminary, be a matter of very considerable interest to illustrate in some detail, the very admirable and uniform manner in which Indian railway accounts and statistics of all kinds are placed before the public, as well as the very perfect and minute system of external financial con-

trol exercised. In these respects, Indian Railway administration has perhaps from the very beginning been well in advance of that in any other country of the world, and notwithstanding the unfortunate circumstance that statistical details of expenditure are somewhat complicated by the unavoidable intermixture of two standards of value, and that some apparent confusion is occasionally created by the non-coincidence of the financial and calendar years, it would not be too much to say that the railway statistical returns of all kinds, published and exhibited yearly under the system enforced by the Indian Government are, on the whole, more perfectly clear, exact, and valuable for every purpose of record and comparison, than any similar returns that have yet been elaborated by any railway or Government authority in existence. It would, however, be impossible to indicate—even in outline—within the very limited compass of such a volume as the present, dealing as it does not only with railways but with every variety of public works—the system and principles on which the elaborate accounts and comparative statistics of Indian railways are compiled; the attempt, moreover, would be a trespass on ground of too special and technical a character.

Initiated on the 18th April 1853, with the opening of the first section of the Great Indian Peninsula Railway, between Bombay and Tannah, a distance of 20¼ miles, the Indian railway system has steadily, and with a judicious rate of progression, expanded, until its total mileage open for public traffic, is now practically equal in extent to that of the United Kingdom. Including all classified denominations, and gauges of line, the mileage of Indian railways, on the 31st March 1892, reached 17,564 miles, of which 1116¾ miles only were laid with a double track, and extensions equal to nearly 1700 miles were in course of construction.

The gauge of all the earlier lines—which, as we have seen, were constructed by companies working under a fixed Government guarantee, was originally established at 5 feet 6 inches, and this still remains the 'standard' railway gauge of India. The first departure from it was in the year 1863, on the opening of 27¼ miles of a railway on a special gauge of 4 feet, built by the 'Indian Branch Railway Company;' afterwards the Oudh and

Rohilkund Railway Company, between Nalhati and Azimgurh, in the North-west Provinces. This line remains a solitary instance in India of a railway constructed on that gauge. In the year 1864, a line from Arkonum to Little Conjevaram, in Madras, was built by the 'Indian Tramway Company,' under a subsidy system, on the 3 feet 6 inches gauge, but was afterwards, in 1878, converted to a width of one metre, or 3 feet $3\frac{3}{8}$ inches.

The idea of superseding the 5 feet 6 inches gauge originally adopted for Indian railways, by the construction of lines of a narrower and lighter description, which could be opened with greater rapidity, and at a less initial cost, had been frequently mooted, but in the year 1870, at a time when about 4600 miles of main trunk lines on the standard gauge had been constructed, the recommendation that a narrower width should be employed in the case of all future lines of railway was made by the Viceroy and Governor-General of India, and supported on the ground of economy. The Indian Government authorities came to the conclusion that a gauge of 3 feet 6 inches was the maximum that should be used in the future, but the precise dimension was left for determination in England, and a committee was appointed to consider the subject, with the result that a gauge of 3 feet $3\frac{3}{8}$ inches, or one metre in width, was accepted as the gauge for future railways. This decision led to a memorable controversy between the advocates for adherence to the original broader gauge, and for strict uniformity in this particular, and those who contended that the evils of a break of gauge had been greatly exaggerated, and that the circumstances of India were such, that the country was practically constrained for the future to be content—either with a narrower and much cheaper kind of railway than heretofore, or submit to a disastrous diminution in the rate of development and progress towards a complete railway system.

This heated and lengthened discussion—which emulated the celebrated 'battle of the gauges,' fought out in the early days of English railways, when Brunel introduced an altered gauge on the Great Western, was attended, however, with little immediate advantage beyond placing on record the views of the contending parties. The Government of India had, in

fact, come to a decision on the subject; the metre gauge was introduced into the country, and in the year 1873, 91½ miles of a trunk line (eventually extended to 1261 miles), viz. the Rajputana-Malwa State Railway, was opened for traffic. From this date the construction of metre gauge lines in India has steadily progressed. They were introduced, on the score of an urgent economy, as the future type for all Indian railways; but notwithstanding the supposed inability, in 1873, of the country to continue the construction of the more perfect, and, in consequence, more costly standard gauge lines, the relative length of railways on the two gauges, built from the year 1873 to 1892, inclusive, have in round figures been as follows—broad gauge lines 5000 miles, metre gauge lines 7000 miles. The main trunk routes having been originally made on the broader gauge, its continued use in a large number of cases became a practical necessity, and India, although it has reaped some possible advantages in the possession of a greater total mileage of railways than it might otherwise so early have enjoyed, has had to submit to whatever evils may have resulted from a break in uniformity.

With the exception of the Rajputana-Malwa State Railway, the metre gauge has been practically confined to feeders of the larger lines, or to more or less isolated systems, and it is probable that the evils of want of uniformity of gauge will be very greatly mitigated or removed, when the aggregate of these lines or systems throughout India are connected together in such a manner as to form a complete internal network of narrow-gauge railways, subsidiary to, and working within, a main framework of trunk lines of the heavier description. There is, in fact, room in India for both kinds of railways. In more than one case, however, injudiciously located metre gauge railways have been converted, almost on the eve of completion to the standard gauge, and the conversion of the Rajputana-Malwa trunk line itself has been powerfully urged. Moreover, the economy and advantage of the continued employment of the metre gauge, even for feeder lines, is still seriously called in question by many persons. In addition to the metre gauge, a small mileage of lines of special abnormal gauges have been constructed in various parts of India, under

peculiar or local conditions, but these lines in no way affect the general railway system of the country.

With regard to the construction of railways generally, in the year 1869 a new policy was inaugurated by the Indian Government. The earlier system of guarantee was abrogated on economical grounds, and it was determined thenceforward to largely or entirely construct Indian railways by direct Government agency. Subsequently, however, the policy of constructing new lines by the aid of assisted companies—working under modified terms more favourable to the State has been resorted to, and in one case, viz. that of the Bengal and North-western Metre Gauge Railway, a line has been constructed by a limited liability company, with a free gift of land, but no guarantee.

The mileage and respective gauges of Indian railways, together with the rates of construction, from the commencement down to the 31st March 1892—a period of practically thirty-nine years, can be best exhibited in the form of the following table, showing the length of lines opened in the several quinquennial periods from 1853 to 1892 inclusive—the last period being short of nine months.

Length of Lines open during Quinquennial Periods—1853 to 1892.

Quinquennial Periods.	Standard Gauge.	Metre Gauge.	Special Gauge.	Total Mileage opened.
	Miles.	Miles.	Mile	Miles.
1853 to 1857 inclusive,	288½	*		288½
1858 to 1862 ,,	1965½	82*		2047½
1863 to 1867 ,,	1493¼	80¼*	27½	1600¾
1868 to 1872 ,,	1410¼	23½*	*	1433¾
1873 to 1877 ,,	607½	1324½	20	1952
1878 to 1882 ,,	1336¾	1396¼	90¼	2823¼
1883 to 1887 ,,	1917	2200¾	113¾	4231½
1888 to 1892 (31st March),	1085¼	2064½	37¼	3187
Total Miles actually open,	10,103¾	7171¾	288½	17,564
Lines under construction or sanctioned on 31st March 1892,				2694¼
Total Mileage open, under construction, or sanctioned on 31st March 1892, ...				20,258¼

* Originally 'Special Gauge,' afterwards converted to Metre Gauge.

It will be seen from this table that 17,564 miles of railway of all classes have been opened for traffic in the thirty-nine years previous to 1892, or an average throughout that period of 450⅓ miles per year, equal to an average rate of 1·44 miles of railway per working day. Excluding the first quinquennial period, the maximum mileage was opened in the years 1883 to 1887, and the minimum in the years 1868 to 1872. In addition to the above it may be mentioned that there were in existence at the end of 1891-92, 37¾ miles of steam tramways outside municipal limits. The classification of Indian railways, and the mileage worked under each class, on the 31st March 1892, are exhibited in the following table:—

CLASSIFICATION AND MILEAGE OF INDIAN RAILWAYS.

Classification of Indian Railways.	Standard Gauge.	Metre Gauge.	Special Gauge.	Total.
	Miles.	Miles.	Miles.	Miles.
State Lines worked by Companies, .	3316½	5088¼	*	8404¾
State Lines worked by the State, .	3491	1146¼	63¾	4701
Total State Lines, .	6807½	6234½	63¾	13,105¾
Lines worked by Guaranteed Companies, ...	2588¼	*	*	2588¼
Assisted Companies, ...	184½	136¼	59	379¾
Lines owned by Native States and worked by Companies, . . .	399½	122	71¾	593¼
Lines owned by Native States and worked by State Railway Agency, .	124	*	*	124
Lines owned and worked by Native States, ...	*	620¼	94	714¼
Foreign Lines, ...	*	58¾	*	58¾
Total Miles, . .	10,103¾	7171¾	288½	17,564

It will be learned from the above table that the State owns 13,105¾ miles out of the total mileage of 17,564, of Indian

railways. This length includes several important lines such as the East Indian, the Scinde, Punjab and Delhi, and the Oudh and Rohilkund Railways, originally constructed by guaranteed companies, but since acquired by the Government under the contract terms. The comparatively small mileage as yet owned by native States will also be remarked.

The total capital outlay against all Indian railways, including that incurred on collieries, surveys of lines abandoned, or not yet begun, on unfinished lines, steamboat services, suspense accounts, and, in fact, on all heads—up to the end of the calendar year 1891, amounted to 22,767 lakhs of rupees, or over 227½ millions sterling at par of exchange.

Excluding the expenditure on collieries and surveys of lines abandoned or not yet begun, but including unfinished lines, steamboat services and suspense accounts, the total capital outlay amounted to 22,676 lakhs of rupees, or over 226¾ millions sterling at par. Deducting, however, for purposes of comparison, the cost of unfinished lines, steamboat services and suspense accounts, the capital outlay on *open* lines of railway—the mileage of the several classes opened and working at the end of 1891, and their average cost per mile were as follows:—

CAPITAL OUTLAY AND COST PER MILE.

Gauges.	Miles open on 31st Decr. 1891.	Capital Outlay.	Average Cost per Mile.
	Miles.	Rs.	Rs.
Standard Gauge, ...	10,047·73	16,347,27,103	1,62,696
Metre Gauge, ...	6,946·68	4,961,69,625	71,425
Special Gauges, ...	288·31	86,13,182	29,875
Total of all Railways, . .	17,282·72	21,395,09,910	1,23,795

The very great difference, as exhibited by the above table, between the cost per mile of the standard gauge lines and that of the metre and special gauges requires some comment. It must not be overlooked that the difference is very largely due to the inferior weight, as well as to the finish and equipment

generally, of the smaller classes of railways, and to the comparative absence on these lines of engineering works of the first order of magnitude. The 5 feet 6 inches—or standard gauge—railways form the main trunk lines of communication throughout India; the metre-gauge lines, with the principal exception of the Rajputana Malwa State Railway, are for the most part subsidiary or feeder lines. On the broad-gauge railways from 11 to 12 per cent. of their total length is laid double, and on all the older lines, forming a large proportion of the whole, the earthwork formation has been made for a double track, as well as the bridge and culvert masonry in many instances. On the metre-gauge, however, there is practically no double line, and little or no provision for doubling the rails has been made. The broad-gauge railways of India are, in point of weight and quality of permanent way, ballasting and fencing, and in great respect also as regards station accommodation, fully equal to the best European lines, whilst the majority of those of the narrower gauge are constructed with light rails of 41¼ lbs. per yard, have as a rule a minimum of station accommodation, and in many cases are unprovided—at least for many years after opening—with full ballast, and are also commonly unfenced. Many of the lines of special gauge are still lighter and less finished in these particulars—especially in station accommodation—and have, moreover, in many instances been laid on ordinary cart roads, with works of a very limited kind.

On the standard-gauge railways, nearly all the heaviest engineering constructions and works of special magnitude are to be met with, whether as regards the enormous bridges over the principal rivers of the country—some of which we have illustrated in previous chapters—or the splendid and costly mountain roads for surmounting the Thul and Bhore *ghâts*, on the Great Indian Peninsula Railway, and the difficult passages through the mountains of Beluchistan on the extension of the Sind-Pishin Railway to Quetta and the Afghan frontier. On the main trunk routes these difficult and costly undertakings had of necessity to be encountered, whilst in the case of the majority of the metre-gauge lines—constructed for the most part as subsidiary and feeder railways—the occurrence of

any specially difficult and expensive works would at once have been an effectual bar to their original construction.[1] To exemplify this, it is only necessary to turn to the tables of large bridges and tunnels, given in Appendices K and L, from which it will be seen in the case of important bridges that for the standard-gauge lines 127,911 lineal feet, or 24¼ miles in length, of large bridge-work, costing 925,25,694 rupees, have been provided, against 21,014½ lineal feet or less than 4 miles, costing 116,42,982 rupees, on the metre-gauge lines, whilst on the latter railways no tunnels of important size will be found, against 45,431 lineal feet or 8⅔ miles of tunnelling, costing 150,45,991 rupees, which have been necessitated on lines of the standard gauge. Again, the average age of the standard-gauge railways is greater than the average age of the metre-gauge lines, and the former have developed and carry a far heavier traffic. Their capital cost, therefore, includes a much larger proportion of expenditure, due to additions and improvements —subsequent to the initial outlay—to meet continually augmenting requirements. It will thus be seen that the actual capital cost per mile, as exhibited in the table, of the broad and metre gauge railways of India, does not fairly represent a true comparison under similar conditions of the relative mileage-cost of the two descriptions of railway.

Turning now to 'working results': the gross earnings on all Indian railways for the calendar year 1891 (the last year for which the information is available) were 2404,02,790 rupees Of this amount 76·56 per cent. was earned by the standard-gauge lines, 22·88 per cent. by the metre-gauge, and the balance of 0·56 per cent. by the special-gauge lines. The following table shows the distribution of the gross earnings under the main heads of account:—

[1] *Vide* 'Indian Railways,' by F. J. Waring, M.I.C.E., vol. xcvii. *Min. Proc. Institution of Civil Engineers.*

Gross Earnings.

Gauges.	Coaching.		Miscellaneous and Steamboat.		Miles Open.	Gross Earnings per Mile of railway open.
	Rs.	Rs.	Rs.	Rs.		Rs.
Standard Gauge,		1240,28,024	48,08,415	1840,61,732	10,047·73	18,318·73
Metre Gauge, .	216,93,010	313,59,838	19,58,026	550,10,874	6,946·68	7,919·01
Special Gauges, .	6,19,367	6,93,304	17,513	13,30,184	288·31	4,613·72
Totals—Rs.	735,37,620	1560,81,166	67,84,004	2404,02,790	17,282·72	13,910

The total 'working expenses' on all railways during the year 1891 were 1130,38,471 rupees, distributed as follows:—

Working Expenses.

Gauges.	Working Expenses,	Miles open.	Working Expenses per mile of railways open.
	Rs.		Rs.
Standard Gauge,	831,03,801	10,047·73	8270·90
Metre Gauge, .	290,82,250	6,946·68	4186·50
Special Gauges,	8,52,420	288·31	2956·60
Totals—Rs.	1130,38,471	17,282·72	6540·60

The percentage of working expenses on gross earnings on all railways taken together was 47·02 per cent., distributed throughout the various heads of service as follows:—

Percentage of Working Expenses on Gross Earnings.

Gauges.	Maintenance, per cent.	Locomotive, per cent.	Carriage and wagon, per cent.	Traffic, per cent.	General per cent.	Steamboat and Miscellaneous, per cent.	Total per centage
Standard Gauge,	12·64	15·09	4·36	6·87	4·05	2·14	45·15
Metre Gauge, .	13·69	17·79	4·21	8·06	6·93	2·19	52·87
Special Gauges,	14·94	20·40	6·08	11·08	9·73	1·81	64·08
Totals,	12·89	15·74	4·33	7·17	4·74	2·15	47·02

The 'net earnings' realised were 1273,64,319 rupees, distributed over the three classes of railways as below :—

NET EARNINGS.

Gauges.	Net Earnings, Rs.	Miles open.	Net Earnings per mile of railway open.
			Rs.
Standard Gauge, . .	1009,57,931	10,047·73	10,047·83
Metre Gauge, . . .	259,28,624	6,946·68	3,732·50
Special Gauges, . .	4,77,764	288·31	1,657·10
TOTALS, .	1273,64,319	17,282·72	7,369·40

It will, from the above table, be deduced that in the year 1891, on every mile of open railway the net earnings of the standard-gauge lines were as one rupee against slightly less than 6 annas in the case of the metre gauge, or as £1 against 7s. 6d.

The return on the whole capital expenditure on open lines, including steamboat services, etc. during the year 1891, was 5·76 per cent. distributed as follows :—Standard-gauge lines 5·98 per cent.; metre-gauge lines 5·04 per cent.; special gauges 5·42 per cent. The mean mileage worked during the year was 17,037·63 miles, and the total results may be summarised as follows :—

GENERAL RESULTS, INCLUDING STEAMBOAT SERVICES AND SUSPENSE ACCOUNTS.

Gauges.	Miles worked.	Capital outlay.	Average cost per mile. Rs.	Gross Earnings, Rs.	Working Expenses, Rs.		Earnings, Rs.	Per cent on Cap.
Standard Gauge,	10,055·82	16,869,18,826	162,696*	1840,61,732	831,03,801	45·15	1009,57,931	5·98
Metre Gauge, .	6,695·22	5,149,13,408	71,425	550,10,874	290,82,250	52·87	259,28,624	5·04
Special Gauges,	286·59	88,09,682	29,875	13,30,184	8,52,420	64·08	4,77,764	5·42
TOTALS,	17,037·63	22,106,41,916	123,795*	2404,02,790	1130,38,471	47·02	1273,64,319	5·76

* Excluding Steamboat and Suspense.

The total number of passengers carried by all the railways in India, during the year 1891, was 122,855,377, and the gross earnings amounted to Rs. 775,37,620, or Rs. 14,110 per mean mile worked. The number of passengers booked per mean mile worked was 7211. The average distance travelled per passenger was 45·98 miles on the standard-gauge lines, and 38·17 on the metre-gauge railways. Of the total number of passengers carried the two lowest classes constituted 97·34 per cent., the second class 2·26 per cent., and the first class 0·40 per cent. of the whole.

The total tonnage of goods carried was 26,158,953 tons, or 1535 tons per mean mile worked, and the gross earnings were 1560,81,166 rupees. The passenger mileage reached 5,226,107, 973 miles, and the goods ton mileage 4,438,992,431 ; the total number of train miles being 60,800,165.

The main results of working all the Indian railways during the year 1891, divided over the three heads of gauge, will be found detailed in Appendix M.

There are, as a rule, four classes of vehicles for passenger traffic on Indian railways, viz. 1st, 2nd, 3rd, or intermediate, and the 4th, or lowest class. The fares charged vary considerably in working, but the schedule of maximum and minimum fares for coaching traffic are as follows :—

	Maximum pies per mile.	Minimum pies per mile.		
First class,	18	12	equals	$2\frac{1}{4}$d. to $1\frac{1}{2}$d. at par.
Second class,	9	6	,,	$1\frac{1}{8}$d. to $\frac{3}{4}$d. ,,
Intermediate,	$4\frac{1}{2}$	3	,,	$\frac{9}{16}$d. to $\frac{3}{8}$d. ,,
4th or lowest class,	3	$1\frac{1}{2}$	,,	$\frac{3}{8}$d. to $\frac{3}{16}$d. ,,

The ordinary fares for the lowest class are from 2 to 3 pies per mile, or from one, to one and a half farthings. A man can, therefore, generally travel by railway a distance of 400 miles within the 24 hours, for the small sum of Rs. 4.2.8, or say, 8s. 4d. at par of exchange. To get over this ground by ordinary road journeys would take him from thirty to forty days, and the humblest traveller would of necessity expend a greater sum for his daily food during this interval ; the generality, even of the poorer class, would probably expend double this amount.

Although the railway passenger classes are so numerous on Indian railways, it was in India that probably the earliest experiment was made of employing only two classes for passengers, such as adopted now for many years on the Midland Railway in England. The Indian Branch Railway Company, afterwards the Oudh and Rohilkund Railway, originally introduced two descriptions of vehicles for passenger traffic, respectively called the 'Upper' and 'Lower' classes, corresponding with the 1st and 3rd classes on English lines. Subsequently, however, an intermediate fare, and a somewhat superior carriage was interpolated into the lower class.

At the end of the year 1891, the number of locomotive engines employed on the main railway system of India (*i.e.* excluding the special gauges) was 3763 in all, or 2535 of standard, and 1228 of metre gauge, and the quantity of passenger and goods rolling-stock, at the same time was as follows :—

Passenger and Goods Rolling-Stock at end of Year 1891.

Classification.	Standard Gauge.	Metre Gauge.	Total.
First-class carriages, ...	463	345	808
Second-class carriages, ...	522	270	792
Third or intermediate carriages, .	233	90	323
Lowest or fourth-class carriages, .	3,565	2,666	6,231
Composite carriages, . . .	644	417	1,061
Miscellaneous carriages, . . .	930	456	1,386
Totals, Passenger rolling-stock, .	6,357	4,244	10,601
Goods vehicles of all kinds, . .	44,370	24,252	68,622
Brake vans, ...	2,067	926	2,993
Total, Goods rolling-stock, . .	46,437	25,178	71,615

It will be of interest also to point out the number of persons of all races engaged on the service of Indian open lines of railway, as they are distributed throughout the various railway departments. At the end of the year 1891 the total number of persons so employed was 260,598, of whom 250,036 were natives of the country, 5936 were Eurasians, and 4626—or 17·75 per cent. only of the whole—were Europeans. The distribution of the above number of persons was as follows :—

DISTRIBUTION OF PERSONS EMPLOYED ON INDIAN RAILWAYS.

Departments.	Europeans.	Eurasians.	Natives.	Total.
General administration, including agency, audit, accounts, stores, medical, printing, police, etc., .	353	451	13,771	14,575
Traffic and telegraph departments,	1567	2197	54,625	58,389
Engineers' department, . . .	486	491	112,001	112,978
Locomotive and carriage and wagon, inclusive of steamboat establishments, ...	2220	2797	69,639	74,653
TOTALS, .	4626	5936	260,056	260,595

Of the 260,595 persons employed, 198,225 were engaged on the standard-gauge railways, and 62,373 on the metre-gauge. The total number of railway stations throughout India was 2427, or 1489 on the standard, and 938 on the narrow-gauge lines. The mileage open (of these two gauges) was 10,048 and 6947 miles respectively, so that the average distance apart of the stations is 6·75 and 7·40 miles.

The efficient training and employment of natives of the country in the responsible positions of drivers or shunters of locomotives, has for many years occupied the careful attention of railway authorities in India; and it will be of interest to the reader to note the gradual but steady increase in this important class of railway servants during the ten years,

1881 to 1890 inclusive, as exhibited by the following table:—

NUMBERS OF NATIVE DRIVERS AND SHUNTERS, 1881 TO 1890, INCLUSIVE.

Class.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.
Drivers, .	278	335	391	456	519	580	650	724	808	826
Shunters, .	269	295	325	382	386	414	433	444	458	472
TOTALS,	547	630	716	778	905	994	1083	1168	1261	1298

Although, for persons who take ordinary care, there is certainly no safer mode of travelling than that by railway, nevertheless, in spite of the most stringent precautions, a certain yearly number of accidents to trains will inevitably occur on every railway, or railway system in the world. The accident returns on Indian railways for the year 1891 may be thus briefly summarised. The number of train accidents per 1000 train-miles was 0·07. Out of the $122\frac{3}{5}$ millions of passengers travelling 56 were killed, or 1 in 2,190,000, and 135 persons were injured. The total number of passengers killed or injured, viz. 191, gives an average of 27 millions of miles travelled for each casualty. Few persons thoroughly realise the extraordinary security of railway travelling. Taking the last Board of Trade returns of railway accidents in the United Kingdom, and deducting the casualties for which the passengers themselves were clearly responsible, it appears that a traveller might expect to make 966,244 railway journeys without mishap, and 169 million journeys without being killed. A reasonably cautious person, therefore, making two journeys per day on every day of the week might hope to escape fatal accident for at least 270,000 years.

One of the most important questions connected with the economical working of Indian railways is that of fuel supply. The three or four thousand powerful iron horses that daily and hourly are traversing some portion of the length and

breadth of the country with so great a rapidity, drawing behind them such immense loads of vehicles, passengers, and merchandise, can only maintain their vigorous life and energy by a prodigious consumption of mineral or vegetable food, in the shape of coal, coke, or wood. In the year 1891, the locomotive engines on Indian railways consumed no less than 1,036,498 tons of coal, and 363,171 tons of wood, coke, or patent fuel. Of the coal consumed 216,822 tons were English, and 782,664 tons were of Indian production.

Although coal was known to exist in India so long ago as the year 1774, and was actually worked in 1775, it is only during the last twenty years—under the stimulus of railway requirements—that any notable development in the exploration and opening up of the chief coal-fields of the country has taken place, and it has been ascertained that the area in India over which the coal formation may be presumed to extend, is not far short of 40,000 square miles. Most of the more important collieries are worked in connection with the railways, and by direct or indirect Government agency. The yearly output of this important mineral, from collieries chiefly situated in Bengal, Assam, the Central Provinces, and the Nizam's territory, reached in the year 1891 a total quantity of 2,118,680 tons, as compared with 997,730 tons in 1881, of which—as we have seen—782,664 tons were burned on the railways, the balance going either to maintain the stocks in hand, or to industrial manufactures. A statement showing the quantity in tons of coal produced in India during the last twelve years, and the distribution of the output over the several provinces of the country is subjoined in Appendix N.

In the year 1857 the Indian Government had opened 288½ miles of railway, which carried during the year two millions of passengers and 253,000 tons of goods. By the end of 1891, 17,283 miles of railway were in operation, which carried during the year nearly 123 millions of passengers, and over 26 million tons of goods. As we have seen, the rates charged for passengers on these railways are as low as one farthing per mile, whilst the goods rates range as low as one halfpenny per ton per mile.

The centralised administration or control of Indian railways, constructed also under a rigidly enforced system of standard

dimensions both for works and rolling-stock, and under a thoroughly efficient and minute supervision exercised by the Government inspecting officers, acting with the widest powers, has been of incalculable benefit to the public, and has freed India from many of those evils which have grown up, and proved well-nigh insuperable, under the exercise of the largely irresponsible powers which in England and America has fallen into the hands of the great railway monopolists. In England, the officers of the Board of Trade, exercising their functions under a very strictly limited legislative authority, have little or no power to *order*; they are for the most part restricted to recommendations, that in many instances are quite insufficient to cope with the vast weight of private and monetary interests to which the recommendations are opposed.

The following extract from a memorandum issued by the India House in 1889, on some of the results of Indian administration during the previous thirty years of British rule in India, will fitly conclude the subject of railways:—

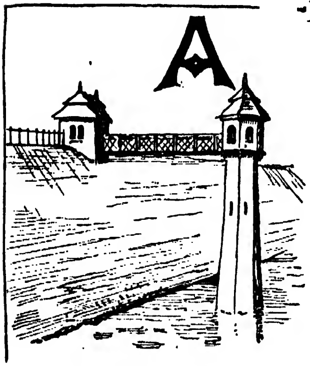
'It is hardly necessary to refer here to the incalculable benefits done by railways, which in time of need carry food from prosperous districts to famine-stricken provinces; or to the impulse given to production and trade when railways carry to the seaports surplus products that would otherwise have found no market, and might have rotted in granaries; or to the enormous addition to the military strength of the country, when troops and material can be moved to the frontier, or to any scene of disturbance, at the rate of 400 miles, instead of 10 miles a day, and at one-sixth of the old cost. Railways have now been made, or are being made, on all the main routes in British or Native territory. The system of military railways on the North-west frontier is nearly completed, and several lines which do not pay commercially have been constructed for the protection of tracts specially liable to visitation by famine. Cross lines and branch lines have still to be made, and during the two years 1886 and 1887, new lines or extensions, aggregating 2228 miles, were opened. In the North-west Provinces and Oudh, the richest and most densely peopled tract in India except lower Bengal, railway extension has progressed so far that it has been stated that no village, except in the Himalayas and hill tracts south of Mirzapore, will be more than 40 miles from a railway station by June 1889, when the Indian Midland Railway, now under construction (1887-88) will be completed.'

WATER-SUPPLY OF TOWNS IN INDIA

CHAPTER I

INTRODUCTORY

Introductory remarks—Early adoption of well-sinking and impounding water in tanks—Method by which the modern water-supply of towns is effected—Ancient water-supply schemes all gravitation works—Absence of pipes, and means of pumping—Sub-soil wells—Roman aqueducts—The 'Pont du Gard'—Advance in modern water-supply arrangements—Increased purity and pressure of the water—Leading principles of modern water-works—Source of water—Rainfall—Consumption of water—Intermittent and constant service systems—Design of water-works—The reservoir—The embankment or dam—Foundation trenches—Puddle and other details—Waste-weirs and arrangements for drawing off water—Straining and screening—Pumping schemes—Conveyance of water—Conduits and pipes—Inverted syphon in lieu of aqueducts—Service reservoir—Settling tanks and distribution.



ALL sections of mankind, raised in the least degree above the lowest level of barbarism, have in every age recognised the supreme importance of a plentiful supply of pure water for the use of the inhabitants of those often densely-populated centres to which we give the name of cities or towns. In modern days, when the nature and causes of most of the diseases which afflict humanity are to some extent known and understood, a pure and ample water-supply is, on rational and scientific grounds, seen to be the *sine qua non* of all sanitary conditions, for it is to a scanty or impure supply of this great necessary of life that the bulk of the epidemic diseases, especially those connected with fevers or cholera, may be traced. All the known civilised communities of ancient Europe or America have left us certain evidence that the provision of water for the

wants of their great centres of population largely occupied their attention. This evidence is given us in the numerous and often vast ruins of aqueducts or other costly works constructed by them for this purpose.

In the East, whether in Palestine, Egypt, Arabia, Persia, India, or China, the artificial water-supply of towns was undoubtedly studied and practised before the dawn of European civilisation.

In India the art and practice of impounding the rainfall in tanks, or reservoirs, is probably contemporaneous with the first introduction of Aryan speech into that country. Owing to the extreme dryness of the climate of India, this was the most readily available method of securing and storing supplies of water in large quantity, especially in those parts of the country where, during the seasons of drought, the natural water-courses are either dry, or exceedingly scanty in volume. In Hindustan, all the larger cities naturally grew up along the banks of the great perennial rivers, where water for the use of the inhabitants was available in abundance. In the case of important towns or villages at a distance from the streams, a supply of water for drinking and domestic purposes would be largely derived from the subsoil by means of well-sinking, an art developed and skilfully practised at a very early stage by all the Eastern races; but in order to obtain those larger volumes of water necessary for the frequent personal ablutions, washing of garments, and other purposes imposed by the religious customs of the country, the construction of artificial tanks for the impounding and storing of water in large masses, would soon be resorted to, wherever the opportunity of so doing presented itself. These tanks, so numerous in India, are generally supplied directly by the rainfall on their own catchment basins, but in some cases they doubtless were fed, either partially or entirely—in early times as at present—by ducts or channels led from the nearest, or most convenient permanent watercourse. In most cases the tanks are found at or close to the villages or towns; these, in fact, having in some measure grown up around them; but in many parts of the country instances are met with of storage reservoirs, constructed at suitable places situated at a distance from the towns supplied from them. In these cases

water from the main reservoir (a greater or less proportion of which may be utilised for the irrigation of the intermediate fields) is led by means of channels, or by enclosed masonry ducts, into one, or into many smaller tanks, or cisterns, situated either in the town itself, or in the neighbouring surrounding gardens, and from these tanks the water is distributed for the domestic service of the population, either by the porterage of a special caste of water-bearers or by the lower-class female population. One of the most familiar sights in India, as indeed generally in the East, is the crowd of female water-carriers, passing and repassing with their earthenware or metal vessels of water gracefully poised on their heads, or collected together in feminine gossip at the margin of well or tank.

The water-supply of towns in modern times is effected by one of two methods, viz. either by natural gravitation or by pumping. In the first method the water is collected from springs, or by impounding flood-waters in reservoirs, at an elevation sufficiently above the level of the town to command the whole or greater part of it, the water being delivered by the natural force of gravity. In the second method the necessary elevation is given to the water by the mechanical aid of steam, or other source of power, applied to the purpose of pumping it, either from rivers, reservoirs, or deep wells. The two methods may also be combined, a portion of the town being supplied by natural gravitation, and the remaining or more elevated portion being supplied by the intermediate agency of mechanical power, to raise or force the water to the required height.

With the exception, perhaps, of some cases where water may have been forcibly raised in buckets or other receptacles from moderately deep wells or other sources, by means of manual or animal power (or even by the aid of wind or water power), all the larger water-supply schemes of ancient times were gravitation works, working at a low pressure. No evidence exists until comparatively recent times of the employment of *pipes* for the conveyance of water under high pressures. Pipes of earthenware or of lead were frequently used in Roman times, but it is evident that neither of these materials could have been subjected to more than a very moderate degree of

pressure. Moreover, until the invention of the steam-engine, there was no means of artificially raising large quantities of water from a low to a high level. Ancient waterworks are, therefore, all of the low-pressure gravitation type of construction.

Subsoil wells were probably the earliest artificial source of water-supply, and allusions to them are to be found in all the most ancient human records. In China there exist numerous ancient 'Artesian' wells of great depth. An 'Artesian' well consists of a bore-hole carried down through some impermeable upper strata, into a lower water-bearing bed, the water in which, being subject to natural hydraulic pressure, at once rises, often to the surface, through the bore-hole. In many parts of Europe, but especially in Southern Italy, ordinary wells of depths often considerably over 100 feet were constructed by the early Romans. For a long time the city of Rome itself was largely dependent on this source of supply, but as the population of the city increased, and the Tiber became contaminated, the conveyance of pure water from great distances was undertaken, as testified by the ruins of many noble aqueducts constructed under the Cæsars, which still remain to fill the mind of modern travellers with wonder and surprise. In almost every country—for any length of time under the dominion of the Roman Empire—the remains of often gigantic water-conduits exist, some of which are even at the present day partially utilised for their original purpose. The Roman aqueducts were, as a rule, boldly constructed works, carrying the water collected from distant springs or lakes, in very direct lines, through tunnels in the hills, and passing over intermediate valleys in masonry channels carried on archwork, often in several tiers one above the other, reaching very considerable altitudes. The aqueducts had a regular gradient, or fall from end to end, usually from 2 to 2½ feet per mile. They contained in some instances enormous quantities of masonry construction, everywhere lined with an excellent quality of cement.

One of the largest Roman aqueducts in Europe is the 'Pont du Gard,' which forms a portion of the conduit for the supply of the town of Nismes in France. This aqueduct has been thus described: 'It consists of three tiers of arches, the lowest

of six arches supporting eleven of equal span in the centre tier, surmounted by thirty-five of smaller size; the whole is in a simple style of architecture, destitute of ornament. It is by its magnitude, and skilful fittings of its enormous blocks, that it makes an impression on the mind. It is the more striking from the utter solitude in which it stands—a rocky valley partly covered with brushwood and greensward, with scarcely a human habitation in sight. This colossal monument still spans the valley, joining hill to hill, in a nearly perfect state of preservation, only the upper part at the north extremity being broken away. The highest range of arches carries a covered canal about 5 feet high and 2 feet wide, shaped in section like the letter U. It is covered with stone slabs, along which it is possible to walk from end to end, and to overlook the valley of the Gardon. The arches of the middle tier are formed of three distinct ribs or bands apparently unconnected. The height of the Pont du Gard is 180 feet, and the length of the highest arcade 873 feet. Its date and builder are alike lost in oblivion, but it is attributed to Agrippa, son-in-law of Augustus, B.C. 19. M. Genieys, formerly engineer-in-chief to the municipality of Paris, estimated that the quantity of water conveyed by this conduit amounted to 14 million gallons per day.'[1]

The most important advances in the modern water-supply of towns as compared with ancient works, are the increased attention given to securing a supply of pure and wholesome water, free from every kind of contamination, and its more systematic and general distribution under high pressures by means of pipes. Increased purity is obtained by a more careful selection of the immediate source of supply, both as regards locality and quality of water, as well as by precautions taken to prevent defilement of the gathering-ground, and by resort to filtration wherever necessary. Many water-supply schemes of considerable magnitude and interest have been carried out during recent years by the municipalities of the larger cities of India, but before proceeding to give the reader an outline sketch of some of the more important of these works, it will be necessary to summarise, as briefly and clearly as possible, the leading principles of modern water-works.

[1] Humber, *On Water Supply of Cities and Towns.*

The Sun is the original dispenser, and the ocean—which occupies more than two-thirds of the surface of the globe—is the ultimate source of all water-supply. Under the influence of the sun's heat, chiefly within the tropics, where the heat rays, being more vertical, are more intense, the surface-water of the ocean undergoes continual evaporation. The aqueous vapour ascending to the upper and cooler regions of the atmosphere, forms those clouds which, driven by established aerial currents over the land, are there under various conditions of temperature and altitude condensed, and fall to the earth in the form of rain, hail, snow, or dew. The great volume of water thus derived—whether absorbed temporarily into the soil, partially retained in lakes, or hastening again to its distant birthplace in the sea, through those surface channels which it has worn for itself, named rivers—becomes in one manner or another available for the service of man, and for the refreshment of all animal and vegetable life. The supply of water, therefore, available for human needs is immediately dependent on the rainfall.

To all ordinary observers nothing appears more variable, uncertain, and inconstant than the fall of rain, even in those countries where, like India, it is plainly seen to be subject to a general seasonable periodicity. Close investigation, however, has clearly established that wherever accurate records, extending over long periods of time, have been kept, it will be found that the rainfall of any particular locality has a mean annual average quantity, due to that locality, during such periods, which will not greatly vary (local conditions remaining the same) during similar periods in the future. It has also been ascertained that if a reasonably correct estimate of this mean annual average for any given place is required, it can only be obtained on condition that accurate records of the actual rainfall have been recorded for a period extending over at least twenty years, and that records for periods of forty to fifty years will furnish a basis for a very close estimation of the real mean annual average. Hence in places where no record of the rainfall has been kept for the necessary length of time, a knowledge of the mean annual fall, with the amount and duration of the principal fluctuations above and below the mean—information

which is necessary to the engineer for water-works purposes—can only be approximately ascertained by comparison with, and deduction from, the records of the most suitably situated neighbouring places, where the rainfall *has* been recorded for the necessary time. It will thus be seen how important a thing it is that a regular and systematic measurement of all rainfall should be carried out in as many selected places as possible in every country. The study of rainfall, its distribution, and the various phenomena connected with its periodical fluctuations in long intervals of time, has occupied the time and attention of many scientific men during recent years, with the object of bringing to light the natural laws by which these fluctuations are governed; and the extreme importance of long series of rainfall observations is now universally recognised by all civilised nations in every part of the world.

The engineer intrusted with the design and construction of waterworks for the supply of a town has first to consider and determine what quantity of water will be required, and has also to take into account the natural growth of the population, so that the works as constructed may be able to meet an increased consumption at least for some years. He will also, wherever possible, design the works with a special view to their future enlargement or extension, at the least subsequent expense. The quantity of water is usually expressed by the average number of gallons consumed every day of twenty-four hours by each unit of the population, or as generally shortly stated, the 'number of gallons per head per day.' This quantity varies considerably, according to the habits and customs of the people supplied, and is dependent upon so many different circumstances that no very certain rule exists by which consumption, where not directly known, can be estimated. In England, owing to improved sanitary appliances, and the large amount of water sometimes used for trade purposes, the consumption, including wastage, varies from 20 to 50 gallons per head per day, but in India from 10 to 20 gallons are more common rates. Water is distributed to towns in one of two ways, viz. under a 'constant,' or under an 'intermittent' service—each of which may be at high or low pressure. In the 'constant' service system the water, in prac-

tically unlimited quantity, is placed at the disposal of the people; the pipes are always maintained full of water under pressure, and can be drawn from them at any time through the taps or valves provided. In the 'intermittent' system cisterns of a certain capacity are provided in numbers as may be necessary, into which the water is turned on during certain fixed hours; the cisterns being provided with self-closing taps which shut off the inflow of the water when they are full. In England, whichever system is employed, the water is invariably delivered into the houses. In India, however, it is more usual, in accordance with the habits and customs of the people, to employ a constant service, either at high or low pressure, delivering the water free of charge from standards erected at convenient places in the public streets and open spaces, but it is delivered also into the houses at special rates whenever demanded.

In Europe, contrary to what might be supposed, it has been found that the average consumption of water, including wastage, is less under the constant than under the intermittent system. As there can be no question as to the greater public convenience, and greater cleanliness of the former, it is probable that in all new works the employment of the intermittent system will be almost everywhere abandoned.

The engineer having estimated the proportion of the annual rainfall that he can reckon upon for his purposes—which will not be more than from 4 to 6 tenths of it, owing to absorption into the soil and evaporation, and having liberally determined the number of gallons of water per head of population that he proposes to provide, can now proceed to the general design of the contemplated works. If a main storage reservoir is contemplated, he can estimate its minimum capacity, so that it may be capable of supplying the requisite quantity of water, not for one year only, but for such number of years as the rainfall data with regard to the consecutive number of driest years may appear to indicate, so that at no time there may be serious risk of the supply running short. He can also determine the exact dimensions of the main pipes or conduits that are necessary. If the water is to be obtained from wells, or from a river by pumping, he can calculate the engine power

and size of pumps required, and fix, according to the special circumstances of each case, all the principal dimensions and details of the project.

He will at a very early stage have turned his attention to the selection of the best position for the reservoir, or for the pumping station, as the case may be, and to the quality of the water available, so as to decide upon the necessity or otherwise, or upon the best and most convenient means, of filtration or purification of the water. The engineer has also numerous other points to consider. In the case of a reservoir its elevation must be such as to command the whole area to be supplied, or if this is not possible, he may have to arrange for the supply of a certain portion of the area by means of pumping. He will have to consider the geological formation of the drainage basin off which the water entering the reservoir will flow, both as regards the material of which the soil is composed, the slopes, and generally all matters which affect the rate of flow or the contamination of the water. He will have to make quite sure that after he has made the reservoir, the water will really flow into and remain in it, and will not escape by underground fissures or by the too porous nature of the subsoil. In most cases, especially in thickly populated districts, he will have to carefully ascertain the extent to which the proposed works will affect the interest of individuals or of communities, by withdrawing from them water or conveniences to which they have established right, and to decide upon the most equitable means of compensation where such rights are interfered with. It will thus be seen that the actual construction of a water-supply project is often the least part of the labours of the engineer responsible for it.

We will suppose, however, that all the laborious initial work has been satisfactorily accomplished, that the exact spot for the storage reservoir embankment has been chosen, and that the nature of the ground on which it has to be reared has been carefully explored by means of trial excavations and bore-holes. It is evident—no matter what may be the material of which the embankment or 'dam' is to be formed—it cannot be merely erected on the surface soil, but some portion at least of its width must be firmly rooted in the ground in such a manner that no water can escape under it, and this can only be ensured

by carrying a certain part of the work down to some natural watertight stratum.

The foundation trench—of whatever width that may be decided, a width that will principally vary in proportion to the height of the embankment—will thus be cut from one side of the valley to the other, until it everywhere reaches a suitable retentive material, and this may in some instances occur only at very considerable depths. Generally, also, it will be necessary to remove from the whole seat of the embankment or dam all surface material likely to be injuriously affected by the action of the water. If the dam is to be a solid one of masonry or concrete, the construction will now be brought up to a more or less general level with these materials, or if an earthen embankment is intended, and the depth is not too great (in which case some intermediate cement concrete might be used) the trench will be filled in with an impermeable material called 'puddle,' formed of a certain quality of clay well worked with water into a homogeneous and retentive mass. This puddle will be carried up like a wall or core, through the heart of the embankment, and will only terminate at a height somewhat above the contemplated water-level in the finished reservoir; its purpose being to stop the passage of any water through the embankment. The earth forming the main body of the embankment—a large portion of which on either side of the puddle-wall will be of a carefully selected character—is at the same time built up systematically in thin layers, and with long slopes on the outer and inner sides of the puddle-wall. On the water-side the face of the earthen slope will be protected from injury by a stone pitching or by other suitable means. Tank or reservoir embankments have for centuries been constructed by the natives of India without any central puddle-wall, but that this omission has not proved hurtful to the stability of many of the works constructed by them, is due to the circumstance that the average height of their embankments is considerably lower, and their general thickness much greater, than in most modern examples constructed by English engineers; whilst the numerous ruins of native tanks which exist give evidence of a frequent absence of the necessary stability in their constructions.

Before commencing the embankment, the engineer will have made due provision for disposing of all water that might collect on the site of the reservoir that would injure or interfere with the progress of the works. This is sometimes done by cutting a 'catch-water' or flood-water channel round the site of the reservoir at a level a little above the margin of the full water-surface, to intercept all the water running off the catchment basin. The channel is constructed with a slight fall, and is dropped into the valley below the embankment. The small quantity of water that may collect from the rainfall on the actual site of the reservoir can then either be allowed to remain, or if in the way can be disposed of by pumping; or the permanent passage to be hereafter used for the discharge of water from the reservoir may be constructed before the embankment is brought up, and utilised.

The particular manner in which it is proposed to draw off the water from the completed reservoir will have been early decided upon, and the engineer will also have fixed upon the most convenient and most economical alignment of the aqueduct by means of which the water is to be conveyed to the town. In almost every case the influx of water into the reservoir, in relation to its consumption, will be such that (unless provided against) it will rise during floods to a height sufficient to overtop the embankment, and as the latter would in such a case be inevitably destroyed, as well as probably much life and property below, it is necessary to render such a contingency impossible. This is done by the provision of a waste or overflow weir, in some part of the embankment—or of several such weirs—made of a total length, and finished off at such an elevation as to carry off all surplus water tending to collect above a certain fixed level, which is usually placed at 6 or 8 feet below the top of the embankment. The water flowing over the waste weir or weirs, is discharged by means of a special channel led into the valley to a point at some distance below the foot of the embankment or dam.

Perhaps the most important matter connected with reservoir construction, especially where the water impounded is very deep, is the manner in which provision is made for drawing off the water. Formerly it was the almost universal practice to

take the discharge-pipes, in one manner or another, through the embankment; generally in its deepest part. They were often carried in a culvert similarly placed. However well and carefully constructed, experience has shown that such expedients are most dangerous to the stability of an earthen embankment. There is nothing more penetrating than water under pressure, and it will inevitably find out every weak spot that may exist. No form of stopping has been found which can in all cases be depended upon to prevent the water under such circumstances, from finding its way along the outside of culvert or other outlets constructed through the heart of an earthen embankment and its puddle wall. The unequal pressure of the embankment is also frequently the cause of irregular settlements, tending to break or dislocate the culvert masonry. In all properly executed works it is now usual to leave the embankment—the stability of which is of the first importance—perfectly intact, and to lay the discharge-pipes of the reservoir in a detached tunnel excavation made in the solid ground, passing them through one or more watertight bulkheads or stops in the tunnel. Careful provision is also made to prevent the water in the reservoir—which may stand at a great height above the tunnel passage—from passing along the outside of its lining, which latter may be either of masonry or of iron. The passage of water through the pipes carried in the tunnel, is controlled by suitable valves and gearing conveniently placed near the bottom of a water-tower built up from a good foundation in the bed of the reservoir; this tower being connected with the shore by means of a service foot-bridge.

There will be but few, if any, cases of water-supply where some method of straining or screening the water before its admission into the pipes or conduits will not be necessary, in order to get rid of the grosser solid matter held in suspension in the water and prevent its choking them. It is usual to pass the water through fine wire-gauze strainers, generally fitted in the water-tower; but these, even if very fine, are often insufficient to exclude fish-spawn. In Bombay, fishes which had no doubt passed through the strainers in the shape of spawn were formerly found in the water-supply pipes, grown to a length of over 4 feet, together with eels of even greater length, and

12 inches in girth. These, and other forms of animal life, dying in the pipes necessarily foul the water, and render it injurious for drinking purposes. Hence the necessity of very great care in efficiently screening the water before its entry into any system of piping.

If the circumstances of the case are such that no suitable site exists for the construction of a storage reservoir at a sufficient elevation to command the town, or if for other reasons it is considered preferable to obtain the required supply of water by pumping, the engineer will resort either to the stores of water contained in the subsoil, and will collect it into wells, sunk to a sufficient depth, from which it can be pumped, or he will draw the water from some permanent river. In either case he will have to provide sufficient engine power to overcome the friction of the water in the pipes, and to raise its whole weight to an elevation sufficient for his purpose. If the subsoil water is to be utilised, he will have to take great care that the wells are so located that the water collecting in them is not liable to contamination from organically impure surface drainage, and in case of river supplies there will be few cases where it will not be necessary to clear the water from sediment and other impurities, by means of settling tanks and filtration previous to its distribution.

Water drawn from river or even well sources can sometimes be supplied by gravitation if the water is tapped at a sufficiently high level to command the town, in which case a weir across the river, and probably a very long delivery aqueduct may be required. Or the water may be delivered by gravitation to the neighbourhood of the town, and then pumped into high service reservoirs, from which, after passing through settling and filtering tanks, it can be distributed by gravitation.

From the source of supply to the town, the water in all cases is conveyed either in cast-iron pipes, or in canals or conduits, open or covered over, or partly in the one manner and partly in the other. The selection of the particular method of conveying the water will be governed by various considerations, among the principal of which will be the greater head required to overcome friction in pipes as compared with canals or conduits. In cases where the source of supply is

situated at a great distance from the town to be served, conduits or open channels will be economical, but the great expense of constructing masonry or other aqueducts across wide and deep valleys will certainly, or probably, necessitate the cheaper expedient of cast-iron piping in the form of an inverted syphon in such situations. Whatever may be the means employed of conveying the water, the pipes or aqueducts will usually terminate in a 'service' reservoir near the town, constructed in such a situation as to command the whole area to be supplied by gravitation. The capacity of this reservoir will be sufficient to contain at least several days' supply of water in order that the aqueduct may be occasionally laid dry for necessary repairs. At the outlet of the service reservoir, meters or appliances for exactly measuring the quantity of water issuing from it will be generally provided, so that any unusual consumption may be at once detected. From this point, the distribution of water over the district to be supplied will be effected by means of main and service pipes, provided at various points with the necessary valves and fittings to control and regulate the flow of water, and with standards or cisterns to deliver it wherever required.

If the water should require cleansing and filtration before distribution, this operation can be carried out at any point between the source of supply and the service reservoir. In order to get rid of the main mass of the sediment that may be contained in the water, it is usually led or pumped in the first instance into a settling tank, or tanks, where an interval is allowed for the sediment to sink, and be deposited on the bottom. The cleared water is then passed into a filtering chamber, and is made to pass through beds of various filtering materials, such as clean pebbles, coarse and fine sand, charcoal, etc., after which it will be ready for distribution.

The reader will now probably have gained a general idea of the more ordinary arrangements made for the water-supply of towns, sufficient at least to enable him to follow the outline descriptions of some of the chief works of this kind executed from time to time in India, to which we will now proceed.

CHAPTER II

BOMBAY AND SHOLAPUR

Examples of Indian waterworks—Bombay water-supply—Rapid development of Bombay—Early studies for improving the water-supply—Rainfall at Bombay—Salsette, and surveys of the course of the Goper—The Vehar basin—The Vehar reservoir—Principal details—Further surveys—The Tulsi scheme—The Tansa reservoir project—Principal details of construction—Cost of works—Opening ceremonial in March 1892—Extract from speech by Viceroy—The Sholapur Waterworks—Ekruk Tank—Low-level canal—Sanitary commissioners' report—Proposals for permanent water-supply—Description of waterworks scheme as carried out—Low rate of consumption—Pumping power—Settling tanks—High service reservoir—Low service—Supply pipe and distribution—Opening of works.

Bombay Waterworks 1856 *to* 1892

THE examples of modern waterworks given in the following pages are arranged chiefly, although not entirely, in the order of their date of construction. In the important capital city of Bombay are to be found the earliest in point of date, as well as the latest, and most considerable of the examples selected for illustration. It will be convenient, therefore, to commence with the water-supply arrangements of that city.

The extraordinarily rapid development in modern times of the population and importance of the city of Bombay, due, not only to the exceptional advantages conferred by geographical position, and the possession of a magnificent natural harbour, but to the energy and commercial activity of its inhabitants, has been accompanied with a more than equally rapid development of its water-supply, so that at the present time there is probably no city of the old world that can compete with it in the abundance and excellence of its water.

Sixty years ago the population of Bombay was only about

250,000 persons. In the year 1850 it had grown to 556,000. In 1857 it was estimated at 700,000, and by the last census of 1891 it had reached a total, including the city, island, and cantonments, of 821,764. Before the construction of the first water-supply reservoir, viz. that designated the 'Vehar Lake' in 1857-58, the population of the city was mainly dependent for nine months of the year on the rainfall caught during the monsoon in old quarry and other shallow excavations which, being situated in the midst of a peculiarly dense and dirty population, became so thoroughly contaminated, especially during the hot season, that a charge 'for clearing dead fish from the tanks' was an item of annual recurrence in the accounts of the town authorities. An almost constant prevalence of malignant fevers and cholera epidemics, and an abnormal death-rate, checking the natural growth of the population, was the inevitable consequence of the extreme pollution of the only drinking-water the lower classes could then obtain.

The deficiency and impurity of the available water became so great as to occasion serious alarm, both to the Government and to the public, and the possible consequences of even a partial failure of the local monsoon rainfall became so appalling, that the most strenuous endeavours were made to search out and discover, within a reasonable distance of the city, some source of water-supply capable of meeting the growing demands of the population. The Island of Bombay, from seven to nine miles long and three broad, is composed of a low tract of clayey land, situated for the most part below the level of the highest tides; lying in a hollow between two low ranges of basalt hills which run nearly parallel with each other at a distance of about two miles apart. At the upper and lower extremities of the island these parallel ranges of hills are united by raised sandy beaches, elevated but a few feet above the level of the sea, and formerly liable to be breached by the waves; a large portion of the present area of the island was consequently at one time a salt-water lagoon, or marsh, until the water was shut out by artificial means, and it was gradually drained. On the north and north-eastern sides, the Island of Bombay is now connected with the adjacent islands of Salsette and Trombay, from which it is only separated by a low mangrove marsh, by several road

causeways, and the railway embankments and bridges, which unite both it and the intervening island of Salsette with the main continent of India. The annual rainfall of Bombay—precipitated entirely during the monsoon season, from early in June to late in September—varies from 80 to over 100 inches. Under such hydrographical and geological conditions a supply of water from the subsoil was obviously out of the question; the only possible source of supply being the collection and storage of the rainfall somewhere within a reasonable distance of the city. So long ago as the year 1828, a proposal was made by Colonel Sykes, chairman of the late Honourable East India Company, for collecting and impounding the surface drainage of the low ranges of hills immediately adjacent to Bombay. It was also proposed to bring into the town water collected and stored on the high land of the neighbouring island of Trombay. Nothing was, however, done, either at that time or subsequently, when under severe pressure of water famine Colonel Sykes's project was revived in the year 1845. In 1846 Captain Crawford, of the Bombay Engineers, pointed out the capabilities of the Goper valley, in the northern island of Salsette, 'The central plateau of which is drained by the Goper and its affluents, and is bounded and intersected by ranges of hills amongst which the occurrence of favourable sites for the storage of water might be certainly predicted.' The distance of this source of supply, and the inevitable costliness of the works involved were serious considerations, so that it was not until the year 1851, when the population of Bombay had reached nearly 600,000 persons and in the following years, that preliminary and detailed surveys of the course of the Goper, and of other neighbouring sources, firmly established the conclusion that the former valley was not only the nearest, but the then *only* practically possible locality from whence an adequate supply of water could be obtained.

It was found that the high ground on which the river Goper takes its rise afforded several excellent sites for storage reservoirs. On more detailed investigation, the basin of Vehar was shown to be sufficiently capacious for the collection and storage of a supply of water judged to be amply sufficient for some years to come. The quantity then considered necessary for the

wants of Bombay was estimated at a daily consumption of nearly eleven million gallons, or 4000 millions annually. At the rate of twenty gallons per head per day this would suffice for a population of 500,000 persons, whereas the population of Bombay was already estimated at nearly 700,000 (1856). It was urged, however, that the proposed supply would be in addition to that derived from existing sources, and that financial considerations were of paramount importance. On the other hand, it was admitted that the extremely rapid rate at which the population was increasing rendered it imperative that the works should be designed with a special view to capabilities of future extension, and that it was most desirable that the reservoir should be made as capacious as possible, in order to contain a reserve sufficient to meet the contingency of a deficient monsoon.

The area draining into the Vehar basin, above the sites proposed for the impounding reservoir embankments, is a little over 6 square miles, capable, however, of being enlarged to over $8\frac{1}{2}$ square miles by the extension of catch-water drains along the western slopes of the boundary hills. It was considered that the mean annual rainfall over the Vehar basin might be safely assumed at 124 inches—or that registered at the sea-level near Tanna—and that deducting $\frac{4}{10}$ of this fall, the remainder, or 74·4 inches, would yield an available annual supply of 6600 millions of gallons from the smaller, and about 9000 millions of gallons from the larger area. The actual storage capacity assigned to the Vehar reservoir was 10,800 million gallons, which, after deduction for evaporation and absorption, would leave an available supply of about 9800 million gallons. As the annual rainfall available for storage on the smaller catchment greatly exceeded the consumption of Bombay, it was calculated that the reservoir would retain a volume of water, as a reserve, nearly equivalent to a two years' supply.

The detailed plans and estimates for the construction of the Vehar reservoir were elaborated between the years 1852-56, and the work of construction was commenced at the end of the latter year. This large artificial lake, when filled to the level of the waste-weir, has a maximum depth of 84 feet. It covers

an area of 1394 acres, or 2·17 square miles, and it stands at 180 feet above the general level of Bombay. The water is impounded by three stone-protected earthen embankments, 42 feet, 49 feet, and 84 feet high respectively. The top width of the highest of these is 24 feet and of the two others 20 feet, the inner slopes in every case being 3 to 1, and the outer 2½ to 1. Each embankment contains in its centre a puddle-wall 10 feet thick at the top, with a batter on each side of 1 in 8. The puddle-wall trenches were excavated from 15 to 25 feet deep, through the surface rock, below all surface springs, and well into the impervious solid basalt below.

The whole of the embankment slopes and top surfaces are covered with a pitching of squared basalt stone twelve inches in thickness, laid on a similar thickness of broken stone. It was considered necessary to cover the top and external slopes in order to protect them from injury by the exceedingly heavy monsoon rainfall of the locality. A waste-weir 358 feet long, having a cross width of 20 feet, and faced with chisel-dressed stone set in cement, was provided for the escape of surplus water. The water is withdrawn from the reservoir through a tower erected near the foot of the inner slope, the upper floor of which is connected with the top of the embankment by a girder foot-bridge in two spans of 85 feet 6 inches. The tower is provided with four inlets, each 41 inches in diameter, placed at vertical intervals of 16 feet. The three inlets not in use are closed by conical plugs, faced with gun-metal, and the fourth or open inlet is surmounted by a wrought-iron straining cage, covered with copper-wire gauze of 30 meshes to the inch, and having a surface area of 54 square feet. The conical plugs and straining cage are each capable of being raised or lowered by a gearing fixed on the top floor of the tower. At the bottom of the tower, or inlet well, and exactly over the orifice of the supply main, a conical seat carries a similar straining cage of copper-wire gauze, having forty meshes to the inch. The water thus passes through two strainers before starting for Bombay.

The supply main, 41 inches in diameter, and 1¾ inches thick is passed below the principal embankment, being laid in a level trench excavated in the rock, and filled with concrete, and is,

therefore, unfortunately inaccessible. That portion of the pipe line passing through the puddle trench, is supported on cut stone masonry set in cement. It is coated with 6 inches of puddle, and is then arched over with 4 rings of brickwork; two teak-wood washers being fixed transversely on the pipes to prevent water from creeping between the latter and the puddle.

The sluice-house is situated at the outside foot of the embankment. Here the large 41-inch main bifurcates into two mains, each 32 inches in diameter. One of these branches only was, in the first instance, continued into Bombay; the quantity of water delivered by it being considered sufficient for the requirements of the population at that time. The length of the 32-inch main from the Vehar reservoir to Bombay is nearly 14 miles, and its water was distributed throughout the town by means of sub-mains and service pipes in the usual manner; delivering water under a head of pressure varying from 165 to 180 feet, into the houses, as well as gratuitously to a large proportion of the inhabitants by means of self-closing conduits.[1]

The supply from the Vehar reservoir was first delivered into the city of Bombay through the 32-inch main in March 1860. The works had been originally estimated to cost £250,000, but the final capital outlay on the project, including subsequent developments, reached a total sum of £650,000, the ultimate draw-off from the reservoir reaching a maximum of about 12 million gallons per day. No very long time elapsed, however, after the completion of the Vehar scheme, before it became evident that further steps would very shortly be imperative to augment the water-supply, owing to the rapidly increasing trade and population of the city, due in great measure to the opening up of the railways connecting Bombay with the interior of the country.

In the year 1868, survey parties were sent out into the island of Salsette, and into the mainland beyond it, to study and report upon the most favourable sites for reservoirs, as well as the most economical means of collecting, storing, and conveying into the town, an adequate supply of water to meet the well-

[1] Abridged from a descriptive paper on the Vehar Water-supply, contained in vol. xvii. (1857-58) of the *Min. of Proc. of the Institute of Civil Engineers.*

foreseen requirements of the near future. In the following year a special commission appointed by Government, considered, but rejected as too ambitious, a proposal for a huge artificial lake at Shivla, with an earthen dam 96 feet high, and a steel main 56 miles long. The commission, however, recommended the construction of a smaller reservoir at Tulsi, situated near the celebrated cave temples of Kennery in the northern part of the island of Salsette. Nothing was, however, definitely decided upon by the town authorities at this time, the Tulsi scheme being considered inadequate; but between the years 1870 and 1872 detailed and more exhaustive studies and surveys were carried out, both on the island of Salsette, and on the neighbouring mainland of the Concan, with a view to ascertain the full extent of the resources practically available for an extension of the water-supply adequate for the growing demands of Bombay. These surveys resulted in the first discovery and recommendation of a site for a reservoir of enormous proportions, situated below the spurs of the Western *ghâts*, on the Tansa river; a gigantic work eventually carried out, and only very recently brought to completion.

In the meantime the proposals for the construction of the smaller water-supply reservoir at Tulsi were again considered, and the execution of this work being determined upon, it was put in hand, and was completed in the year 1879. The Tulsi reservoir provided the town with an additional 4½ millions of gallons per day, raising the total daily consumption of water to 16½ million gallons. This was, however, but a mere temporary slaking of the ever-growing thirst of the city. Within 4½ years—that is to say, as early as the 10th August 1883, a motion was proposed and carried at a meeting of the Municipal Corporation to the effect, that the water-supply available from the Vehar and Tulsi reservoirs being only sufficient for the ordinary domestic wants of the town, apart from its trades, industries, and sewerage system, it was absolutely necessary to provide an additional and permanent supply from a high-level source, which would give the city a continuous supply at full pressure. Whereupon the Municipal Commissioner was called upon to furnish the Corporation with a new scheme for such increased supply.

The exhaustive surveys and studies made in 1870-72, had demonstrated that the construction of the Tansa reservoir scheme would be in the nature of a final settlement of the question of water-supply for Bombay, and this scheme had now come within the range of practical municipal politics. The Municipal Commissioner accordingly recommended its adoption, and that a working survey and detailed estimates should be undertaken. This recommendation was accepted; a sum of £10,000 was voted for preliminary expenses, and on the 19th November 1885, the Corporation passed a resolution according sanction to the construction of the Tansa waterworks, estimated to supply the town with a daily supply of 17 million gallons, at a cost of £1,230,000. The execution of this magnificent project, which ranks amongst the foremost examples of modern engineering undertakings, was commenced in January 1886, and was opened with great ceremony by the Viceroy and Governor-General of India, on the 31st March 1892.

The Tansa reservoir is situated at a distance of about 55 miles from Bombay in a north-westerly direction. It lies on the mainland of the Concan, below the spurs of the Western *ghâts*, in a considerable valley bounded by low hills, distant about 7 miles from the Atgaum station of the Great Indian Peninsula Railway. Here a mighty masonry dam, or solid wall of artificial rock, stretching for nearly 2 miles across the Tansa country, and intercepting two considerable rivers, has been reared, forming behind it an immense deep artificial lake, having a waterspread covering from 6 to 7 square miles, formerly a dense jungle. The catchment area draining into this lake is 52 square miles of hilly country.

The dam, which is built of rubble masonry, is one of the largest in existence, being surpassed only in point of height by two or three large masonry dams in France. It contains no less than 11 millions of cubic feet, or 407,408 cubic yards, of masonry, a quantity sufficient to build a wall 104 miles long 10 feet high and 2 feet thick, or to construct a fortification round the whole island of Bombay, 10 feet high and 6 feet thick. The duct leading the water from the reservoir is 55 miles long, consisting of about 23 miles of masonry conduit, carried at numerous

points on massive aqueducts, 27 miles of iron main 4 feet in internal diameter, about 4 miles of tunnel, and nearly a mile of girder bridges. This gigantic work, which may be regarded as the finest town water-supply scheme in the world, has been made capable of providing a generous supply of pure water to a larger population than Bombay is likely to possess for twenty years to come. It was estimated to supply 17 million gallons of water per day, but, as a matter of fact, can easily deliver from 20 to 21 millions. It is calculated that during the hot season of 1892, and subsequent years, the water-supply of Bombay from the Tansa, Vehar, and Tulsi reservoirs (allowing for a reduced draw-off of 9 instead of 12 million gallons from Vehar, which had hitherto been overtaxed) will reach from 30 to 32 million gallons per day, as against 16 millions available in the previous year—or at the rate of, at least, 40 gallons per head of population per day. By laying an additional main from the reservoir, the water-supply from the Tansa lake as constructed, can at any time be increased to 26 million gallons per day. Nor does this exhaust the special provision made for the future. By raising the height of the dam, to an extent duly provided for, the available storage capacity of the reservoir can be increased so as to supply no less than 68 millions of gallons per day.

The estimated cost of the Tansa water-supply project was £1,230,000. It has actually cost £1,500,000, or a crore and a half of rupees, and takes rank as the most costly municipal work carried out in India up to the present time. On the occasion of the formal opening of the water-works, in the presence of an immense concourse of people on the 31st March 1892, the Viceroy and Governor-General of India is reported to have remarked as follows: 'The benefits of such a supply of water to your great and growing population cannot be overrated. It is on record that, 200 years ago, a traveller who visited the island of Bombay declared not only that provisions were scarce and bad, but that the unhealthiness of the water bore a just proportion to the scarcity and meanness of the diet. It is a pity that we cannot recall that traveller to life, and show him your splendid markets, which a predecessor of mine has declared to be finer than those of any great city of Europe,

and the works which we are to open this evening. There will not be a resident in the city, from His Excellency at Malabar Point, to the dweller in the humblest native bazaar—who will not be a gainer by what you have done. There is no result of European civilisation in India, which I look upon with more unmixed satisfaction than I do upon the great water-works, which so many of our principal cities have lately called into existence. I never look at a stand pipe in a dusty street without feeling that here at least is something which our civilisation has done for the country, and which has conferred upon it an absolutely unmixed advantage. . . . I am glad to congratulate your municipality on the readiness with which, as the representatives of the ratepayers of Bombay, they have faced the responsibilities of this great enterprise. There is, however, a special reason for which it is satisfactory to be able to dwell on the success which has attended municipal self-government here. Bombay may claim for itself the credit of having been the city which was the first to introduce into India a true measure of municipal self-government, and when the history of municipal institutions in this country comes to be written, the Bombay Council Act of 1872, which for the first time gave to your citizens a corporation, elected in great measure by the ratepayers of the city, will certainly be regarded as the most important departure of this kind which has yet taken place in India. The completion of these works proves that the municipal resolution of 1872 gave to your city something more than an ingenious paper constitution. It gave to it a civic body capable of seeing the necessity of such a project as this, capable of undertaking it, capable of carrying it through under the supervision of its own officers.'

As an evidence of the firmness and stability of the financial credit of the corporation and city of Bombay, it may be stated that in the year 1885, when the Tansa water-works scheme was determined on, the municipality was in debt to the extent of £1,335,515, and its paper stood at 100¾. In 1892 the debt, after the completion and payment for the works, stood at £3,565,255, and its paper at nearly 114.

Sholapur Waterworks, 1879 *to* 1881.

The water-works carried out for the supply of Sholapur, the chief town of the Sholapur district of the Bombay Presidency, is an example of a small but very valuable and effective scheme. These water-works were commenced in the year 1879, and were practically completed early in 1881. The population of the town, as given by the census of the latter year, consisted of 59,437 inhabitants, of which 57,000 were reckoned as permanent residents within the area commanded by the water-supply.

At a distance of about 4 miles north of Sholapur is situated the 'Ekruk' tank, one of the largest of the reservoirs undertaken by the Government for irrigation purposes. This reservoir—the details of which are given under head Irrigation works in the Bombay Presidency,[1] was commenced in the year 1866, and in the year 1871 the low-level canal—one of the principal irrigation canals fed by it—was brought into operation. This low-level canal passes round the town of Sholapur at a distance varying from a ½ to 1 mile from the outskirts, or from 1½ to 2 miles from its centre. Before the date of the opening of the Ekruk low-level canal, the town population suffered greatly from the insufficiency and impurity of the water-supply, then derived solely from local wells and surface tanks, supplied by a very precarious and uncertain rainfall; but the opening of the canal greatly improved this state of matters, notwithstanding its inconvenient distance from the larger portion of the town. The beneficial effects were especially marked in the year 1876, when the total rainfall fell as low as 10½ inches. The Sanitary Commissioner to the Government of Bombay, in his report for that year, remarked as follows:—'I may incidentally mention that had the Ekruk tank and canal not been in existence, the town of Sholapur must during this year perforce have been deserted, as all the ordinary supply of water had dried up, and the people were entirely dependent on the canal.'

From so far back as the year 1868, several proposals for a permanent water-supply for the town had been made; the

[1] *Vide* p. 208.

water to be taken either direct from the Ekruk reservoir, or from the canals derived from it, but beyond studies and estimates nothing was practically done until the year 1878, when the municipality decided to adopt the scheme since carried out and when the necessary funds were easily raised in the open market by a loan duly authorised by Government.

The existing water-supply scheme at Sholapur is essentially as follows:—The water is drawn from the Ekruk low-level canal, at a site situated in the fifth mile of its course, about a mile and a half from the centre of the town, and is passed at once into a settling tank, from which it is pumped direct through a rising main into two service reservoirs placed at different levels within the town, from which, under a constant service, the distribution is effected by gravitation. The population estimate, according to a return corrected up to 1872, was taken at 50,666 persons, and a daily allowance of 5 gallons per head was assumed—or a minimum daily demand of 253,330 gallons. This low rate of consumption was estimated under the consideration that the numerous wells and small tanks in and about the town would be still available for washing purposes. In the year 1881 the actual quantity of water consumed, which admitted of simple and accurate measurement, was recorded, and it was found that the actual average daily consumption per head, for the eight months May to December, was 4·52 gallons only, and the average daily consumption in each month was 257,005 gallons; the largest daily consumption being 5·14 gallons per head during the month of May.

It is certain, however, that during the first year, the population would draw more largely from the older sources of supply than they would do later, when the convenience and greater purity of the new water was more fully appreciated, and it would not in India, in ordinary cases, be sufficient to estimate the average consumption, even of a small uncommercial town, at so low a rate, without special provision being made for its augmentation during the hot months, or in times of drought and emergency. This, however, was done in the case of Sholapur. The water is taken from a permanent canal, derived from a large reservoir, in which the supply—so far as that town is concerned —is practically unlimited, and the pumping power—to provide

primarily against breakdown—was furnished in duplicate, so that a doubly increased consumption of water could on necessity be provided for.

Close to the Ekruk low-level canal, from which the water is drawn through a 9-inch pipe, fitted with a sluice-valve for regulating the supply, and a meter for measuring the flow—a settling tank is constructed. This tank is square in plan, measuring 146 feet on each side at the bottom level, and 148 feet on the top. The available depth of water, after allowing a space of 9½ inches deep for deposit, is 9·60 feet. The tank holds 1,292,705 gallons, or rather over five days' estimated consumption. It is constructed entirely in excavation, carried through gravels and soft rock; the sides of the excavation being protected by retaining-walls of rubble masonry, carrying a parapet. The floor is formed of concrete, guttered to facilitate the cleaning and scouring out of the deposit, which is effected through a scouring-pipe fitted with a sluice-valve. From this settling tank the water is pumped by two direct-acting 'special' steam pumps, capable of being worked singly or in combination. Each pump is capable of raising 200,000 gallons in ten hours, and delivering the same to a height of 160 feet (including head due to friction in pipes), through a rising main, 10 inches in diameter, and 8500 feet long, when working at thirty-three strokes a minute. The water is pumped into a high service-reservoir situated on the highest ground in Sholapur, distant 8125 feet from the pumping station. This reservoir is circular, having a floor diameter of 95 feet, and a total capacity of 96,399 cubic feet; the available capacity being 88,193 cubic feet, or 549,442 gallons, which is equivalent to rather over two days of the estimated daily demand.

Close to the Bijapur, or northern gate of the town, a branch from the 10-inch rising main is taken off to a low-service reservoir, which is situated at a distant of 5800 feet from the engine and pump-house. This reservoir, which supplies the town, with the exception of the higher portions and suburbs, commanded by the high service, is similar in details of construction to the high-service reservoir. It is circular in plan, having a central pillar 10 feet in diameter at base, and eight arched radial walls, which support a roof of T irons and corrugated iron sheets. The thrust of the arches in the radial walls are

taken by buttresses projecting from the external wall, which also serve to strengthen the latter.

The diameter of the low-service reservoir is 82 feet on the floor, and 85½ feet at full supply-level, which is 12 feet above the lowest bottom. The external wall is 10 feet high; is constructed of uncoursed rubble masonry, faced with coursed work on the outside face; it is 6 feet thick at the bottom, and 2 feet 6 inches at the top, the interior face having a batter or slope of 1 in 12, and the external face a curve of 17 feet radius. The floor of the reservoir is situated at a height of 58½ feet above the floor of the settling tank, and its total capacity is 71,224 cubic feet, of which 68,711 cubic feet, or 1·69 days of the estimated daily demand is available.

The supply pipe, 10 inches in diameter, discharges over the reservoir wall into a small chamber, from which the water passes over a ledge or weir into a second chamber, and thence escapes through an opening into the main reservoir. The main 10-inch distribution pipe, and a cleaning or scouring pipe—the latter carrying a vertical overflow—are each provided with sluice-valves situated inside the reservoir, and worked from above. They are both carried through the concrete foundation below the main enclosing wall. Sluice-valves are fixed on the main, so as to admit of a supply from either reservoir being cut off when water is being pumped into the other. Frequent air-valves, along the line of piping, and a reflux-valve, situated close to the northern gate of the town; about 3000 feet from the pumping station, are also provided. Upwards of 33,000 lineal feet, or about 6¼ miles of sub-mains and service-pipes, carry the water over all the principal parts of the town and suburbs, and are furnished with the necessary sluice-valves, so as to render each part of the distribution independent. The water is delivered to the inhabitants by means of numerous stand and pipe-posts, fitted with convenient push-cocks. The pipe-posts are each fitted with twelve taps, and are only placed in localities where the population is most dense, in order that a number of people may be able to draw water at the same time.

The Sholapur Waterworks were opened with some ceremony by the Governor of Bombay on the 22nd July 1881. The total initial cost of the project as completed was £21,718, or £161 short of the original estimate.

CHAPTER III

MADRAS AND NAGPUR

Madras Waterworks—The Seven Wells supply—The City Waterworks—Outline of projects—The Red Hills reservoir and feeders—Details of Madras City water-supply—Injuries from floods—Insufficiency of scheme—Opening of works, and improvements suggested—The Nagpur Waterworks—Population of Nagpur—Old sources of water-supply—Native reservoir at Ambajhari—The new project—Details of execution—Puddle trench and wall—Earthworks of new embankment—Waste weir—Arrangements for withdrawing water—The straining and regulating tower—The syphon discharge pipe—The main to the city—Completion of works—Later supplementary supply for higher parts of the town, and for civil station—Principal details and particulars of the new project.

Madras Waterworks, 1866 *to* 1872.

By the census of the year 1891 the city of Madras and suburbs contains a population of 452,518 persons. It depends for its water supply on two separate and distinct sources,—one being the 'Seven Wells' Government Waterworks, supplying Fort St. George, the shipping, and various Government institutions and offices,—the other being the 'Madras Water-works,' which is the main supply of the city, and is under municipal control.

The Seven Wells waterworks is a very early project, having been initiated 120 years ago, or in the year 1772, by a Captain Baker, who constructed it under a contract with Government, by which he undertook for a period of seven years to supply, and keep always full, certain reservoirs in the fort, containing sufficient water for 6000 men for four months, at the rate of three quarts per man per day. In the year 1782, the works were purchased by Government for the sum of £10,500. Including this sum the total cost of the Seven Wells water-supply amounted to £42,492. As originally constructed the supply was confined to the garrison of Fort St. George, but it

has since been extended to nearly all the military institutions and buildings in the Presidency town.

The Seven Wells premises or 'compound' is situated about a mile from the sea, and nearly two miles from the Fort and Penitentiary, which are the farthest points to which the supply extends. On these premises there are now 10 wells, each 16 feet in diameter, varying from 23 to 29 feet deep, from which the water is raised by means of 'Picottah' levers into cisterns, and passed through a filter, measuring 48 feet by 30 feet by 6 feet. From the filter the water is again raised into two main cisterns, each holding about 2000 cubic feet, and thence is conveyed by gravitation through lines of cast-iron pipes, varying from 5 to 3½ inches in diameter, to the various points of distribution, the principal of which are the gunpowder factory, clothing and medical store, arrack distillery, bullet factory, Commissary-General's office, Fort St. George, the Ordnance Lines, and Penitentiary. The Seven Wells waterworks discharges over 140,000 gallons a day, or 51¼ million gallons a year, at an annual cost of about £1200. During the long period that the Wells have been in operation they have shown no signs of failure, and it is estimated that should a further supply of water be necessary it could easily be augmented to three times its present amount.

The inception of the Madras City Waterworks, under the control of the Municipality, dates as far back as the year 1866. Long before that year, however, the great impurity of the drinking water obtained from the numerous wells scattered all over the town, which formed the only source of supply, was fully recognised. In the year 1855 an extensive irrigation improvement scheme, estimated to cost nearly £434,000, was proposed, and in combination therewith the surplus water from a number of large irrigation tanks or reservoirs was to have been stored in a reservoir situated about 8 miles from the town, and conveyed by an open channel or canal into two basins in Madras, from whence it could be pumped into settling reservoirs and thence passed into the mains for distribution. No action was taken on this proposal, but in the year 1861 a somewhat similar project was brought forward, and an engineer officer was appointed to report on it, without, however, leading to any practical results.

By the year 1863, in accordance with orders from the Madras Government, plans and estimates were elaborated for an improved scheme which had for its object the enlargement of two already large irrigation reservoirs, with a view to increasing their storage capacity for irrigation purposes, as well as to provide the city of Madras, its garrison and public establishments, with an abundant and wholesome supply of water. The Government portion of this scheme was originally estimated to cost £61,176, and provided for the construction of an open channel about 7½ miles long to deliver the water from the nearest of the two reservoirs to a point near Madras, the Municipality being left to provide for and construct the necessary distribution works, estimated to cost £128,000. The general scheme was approved by the Government of India in 1866, and subsequently sanction to a municipal loan for the construction of the distribution works was accorded; the municipality being required to pay for the supply of water delivered from the reservoirs at a fixed rate.

The City Waterworks, as carried out, has for its immediate source a large irrigation reservoir known as the 'Red Hills Tank,' situated about 8 miles north-west of Madras. This reservoir is fed by a channel from the river Kortalayar, which passes through a reserve reservoir called the 'Cholaveram Tank,' before reaching Red Hills. The Kortalayar river itself has its origin in the surplus escape of the huge 'Kaveri Pauk Tank,' which is fed from the river Palar.

At a point on the Kortalayar river, about twenty-two miles from the sea, an *anicut* or weir is constructed, diverting the water into a channel which, after a course of about eight miles, enters the Cholaveram reservoir, and issues at a point two miles distant from its entry by another channel over two and a half miles long, which conveys the water into the Red Hills reservoir. The water for the city supply is drawn from this reservoir through six sluices, three of which are at the lowest level, the remaining three being placed above at 4 feet intervals. The discharge is received into a circular basin 80 feet in diameter, and, falling over a shutter-weir, passes into an open canal 3 feet 6 inches deep, originally calculated to deliver about 24 gallons per head per day for a population of 545,000

persons. This channel passes in a south-easterly direction through cuttings, and on embankments, for a distance of nearly seven miles, with a fall of only 3 inches per mile, and delivers the water into a circular well, 22 feet in diameter, situated near Madras. From this well, or 'masonry shaft,' a 42-inch main-pipe extends towards the city for 4455 feet, and then divides into two mains of 36 and 30 inches respectively. The water is distributed to the population by means of numerous cistern fountains, public standards, and wall taps, as well as into the houses when demanded.

In preparing its distribution scheme, the Municipality decided to adopt the principle of distribution by natural gravitation in order to avoid the permanent expense entailed by the use of steam-power for raising the water, and delivering it under artificial pressure. This economy, however, was only gained by a considerable sacrifice in the quantity of water, the latter having to be drawn off from the Red Hills reservoir at a much higher level than that originally contemplated. The settling tanks originally proposed were also discarded. It had been intended that the open channel should have a permanent current; but owing to the intermittent system of supply which the altered circumstances imposed, the water in the channel was frequently dammed up for long periods of twelve hours at a time, the bed of the channel being thus virtually converted into a settling tank, with a consequent rapid silting up, and noxious growth of vegetation, together with numerous other attendant evils.

The supply portion of the project appears from the commencement to have suffered severely from the effects of floods of unexpected severity, and from original errors in the methods of construction employed in raising the older embankments of the Red Hills and Cholevaram reservoirs, which entailed very heavy outlay to render the new work secure.

Water was first supplied to the city from the Red Hills reservoir in May 1872, but it was soon universally admitted that the supply system was far from satisfactory, and that the works needed considerable remodelling. The principal improvements suggested appear to be, an off-take from the Red Hills reservoir at a lower level; a closed pipe line to Madras

in place of the open channel, together with the much needed pumping and filtering works. A project for placing the water-supply works of Madras on a more satisfactory footing was prepared in the year 1877, but the Municipality was not in a position to vote the necessary funds for the purpose. Up to the year 1881 the cost of the original water-supply scheme, for a consumption of about 325 million cubic feet annually, had amounted to £143,000.

Nagpur Waterworks, 1869 *to* 1873.

A water-supply scheme possessing many interesting features is that projected and carried out between the years 1869 and 1873 at Nagpur, the capital city of the Central Provinces. Previous to the completion of these waterworks the population of the native city, which then numbered over 80,000 persons, derived their supply of water from a large number of wells sunk in the basaltic and metamorphic rocks on which the town is built. The greater number of these wells yielded a brackish water, so impregnated with salt as to be absolutely unpotable. A considerable additional supply was obtained, first from the 'Jama Talao,' an old native artificial tank adjoining the city, the water from which was greatly polluted by the surface drainage of a thickly inhabited gathering-ground; and second, from an old reservoir situated at Ambajhari, four miles from the city, from which water was conducted by a line of stone piping; but the works in connection with which had in course of time become greatly decayed, and almost useless.

In 1869, after the nearly total failure of the rains of the previous year, the sufferings of the native population of Nagpur, from the scanty and impure nature of the water-supply, had become so great, that energetic measures were taken to ascertain the best means of furnishing the city with an abundant and wholesome supply of water, and, after careful study and examination of the available sources of the neighbourhood, it was eventually decided to remodel and greatly enlarge the old and decayed native reservoir at Ambajhari, and render it capable of supplying a permanent and sufficient quantity of water for the wants of at least the largest portion of the

native city. As this old work is a characteristic example of native water-supply engineering, and is, moreover, one which has been entirely obliterated and lost in the modern scheme which has superseded it, a brief description of its original essential features may be of interest.

The native reservoir at Ambajhari was constructed upwards of a hundred years ago, under the Bhonsla Rajahs of Nagpur. An earthen embankment, faced with a vertical wall of rubble masonry, was reared across the valley of the Nag river (from which the city of Nagpur derives its name), about 4 miles south-west of the city, and near the small village of Ambajhari. This name, meaning the 'spring of the mango grove,' points to the probable existence of a considerable natural spring or springs at this place, which may have led to the choice of the site for the reservoir. The embankment across the Nag valley was 2568 feet long, 20 feet in extreme height, and of an average height of 12 feet. It was 40 to 60 feet wide on the top, with a back slope of 1½ or 2 to 1. The vertical masonry wall on the water-face was built of basalt-stone, with numerous semicircular or octagonal projections, or bastions, of similar character.

Near the deepest portion of the reservoir, situated somewhat towards the northern end of the work, the water was withdrawn through a masonry passage, carried at a low level through the embankment. This masonry passage projected into the reservoir for some distance beyond the line of the face-wall, terminating in a series of steps. On either side of the projection a broad flight of stone steps led down to the water from the summit of the embankment. The discharge of flood-water was provided for by two escape or waste weirs, one 100 feet long, situated at the south end of the embankment, and a smaller one, 28 feet long, at the extreme north end. The reservoir, when filled to the escapes, had a water area of 237 acres, and contained about 80 millions of cubic feet.

The arrangements for regulating the discharge of water were as follows:—On the outer steps terminating the projection into the reservoir of the masonry discharge passage was a series of five holes at different levels, closed by wooden plugs. The highest submerged plug being withdrawn, the water

flowed into a well or chamber (situated in the body of the embankment), the water in which was maintained at a few feet lower than that in the reservoir by opening one or more of a series of seven issue holes; also placed at different levels in this chamber. These holes communicated through a vertical passage with the lower part of a second small well, placed immediately behind the first. From near the bottom of the second well the masonry passage through the main portion of the embankment issued, and by closing this single outlet, water could at any time be cut off from the main passage. The flow of water was further regulated by a third well or chamber, provided with another series of holes and wooden plugs, and an escape, situated on the discharge line, a short distance beyond the foot of the embankment slope. Provision also seems to have been originally made for collecting the water from the springs below the reservoir into this latter well.

The water, when clear of the embankment and regulating chambers, was conveyed to the city through a cut stone pipe, 4 miles in length, formed of a series of sandstone blocks, each 2 or 3 feet long, and 18 inches or more, square, with a hole, 9 inches in diameter, bored through it. The stone blocks were socketed together, the joints being laid with specially prepared mortar, and the whole was enclosed in basalt rubble masonry. Along the course of this pipe-line—which was somewhat irregular—frequent water-towers or cisterns acted as air-valves, and at the same time reduced the head of water, which was allowed to escape through openings, provided with plugs, in the sides of the tower. The water was delivered to the city on the intermittent system—into small cisterns, each provided with holes in the bottom (closed by the usual wooden plugs), which communicated with service-pipes of unglazed earthenware.

The design and construction of this old work exhibited considerable skill in many particulars—especially in the adaptation of the pressure of the water to the strength of the masonry and other piping employed. In 1869 these old constructions were in a very ruinous condition, and owing to heavy leakage on the pipe-line, together with evaporation from the small depth of water retained in the reservoir, the latter occasionally

ran dry during the hot months, so that as a source of supply for the city of Nagpur the works had become practically useless.

Among the reasons which influenced the selection of the old Ambajhari reservoir site as a suitable position for the contemplated new works, were the following: It was found that above the reservoir there was an uncultivated gathering-ground of over 6½ square miles, consisting, for the most part, of only lightly covered trap and other basaltic rocks, thus furnishing a very clean and favourable surface from which to collect the rainfall. The elevation of the site of the old reservoir was moreover sufficient to command all but a comparatively small portion of the native city by means of gravitation works, and admitted in other respects of the construction of a very extensive supply scheme at a moderate outlay.

The new project, elaborated in 1869-70, and subsequently brought to completion in the year 1873, contemplated the following main works, viz.: A puddle-trench excavated through the heart of the old embankment, and cut for several feet into the solid rock beneath, filled in with good retentive puddle to prevent all leakage. An embankment raised about 17 feet higher than the old one, completely burying in its centre the whole of the old work, including the masonry face-wall. A new waste-weir, having an elevation and discharge section, adapted to the altered conditions. Suitable arrangements for withdrawing and controlling the exit of water from the reservoir—now greatly enlarged by the raising of the embankment and escape-weir—and in due connection therewith, a main of cast-iron pipes, about 4 miles long, from the reservoir to the city, together with a certain initial provision of distribution-pipes and self-closing standards, the whole being estimated to cost £36,554.

The execution of these works was commenced in the early part of the cold season of 1870. The centre of the puddle-trench through the old embankment was placed at a distance of 45½ feet from, and approximately parallel with, the old masonry face-wall. This trench was 3099 feet long, with an average depth of 25 feet, and an extreme depth of 36 feet.

It was excavated with side slopes on each side, into which steps were cut, up which the numerous body of labourers employed carried their basket-loads of earth. A portion of the earth excavated was deposited to form a slope of 2 to 1 in front of the old face-wall inside the reservoir, and the remainder was placed so as to form the base of the new outer slope. The solid rock bottom was met with at depths varying from 3 to 14 feet below the natural ground-level, and into this rock the puddle-trench, 5 feet wide, was cut until everywhere a sound and impermeable strata was reached. During the execution of the work the water in the old reservoir stood from 15 to 20 feet above the lowest part of the excavations, and the leakage from the reservoir, or from underground springs, was kept down by steam-pumping. The puddle-wall was built up with clay brought from a distance of about 3 miles; the total quantity transported and utilised being 900,000 cubic feet, or 33,300 cubic yards. The clay was deposited in the trench in thin layers of 6 to 8 inches thick, and was well kneaded and worked up with water, to ensure a perfect consistency throughout the mass. The width of the clay-wall—which was brought up through the entire height of the embankment—was 5 feet both at top and bottom, widening out gradually to a maximum width of about 10 feet on the line of natural ground-level.

The earthwork of the new portion of the embankment was everywhere joined into the old work, by means of stepped trenches deeply cut into the latter, and above the line of the old masonry face-wall a *berm*, or horizontal bench of earthwork, 9 feet 6 inches wide, was constructed, in order to relieve the wall from too severe a pressure. The finished embankment is 7 feet 6 inches wide at the top, finished off with edge curbs of rough stone. The inner or water face—everywhere protected with a layer of hard stone pitching 1 foot thick—is formed of two slopes, of 2½, and 2 to 1 respectively, separated by the horizontal *berm*, or flat, above alluded to; having its surface only a foot above the summit of the old masonry wall. The outer slope was made with an inclination of 2 to 1, and was turfed. The total height of the new embankment was 53 feet above the lowest bottom of the puddle-trench, and 17 feet 4 inches above the top of the old work. The new portion

contains nearly 3 million cubic feet, or 107,400 cubic yards of earthwork.

At the southern end of the work a new waste-weir, 13 feet 4 inches higher in level than that of the old reservoir, was constructed, consisting of a curved wall of masonry 200 feet long, protected by side walls 120 feet in length. The crest of the weir was placed 6 feet below the top of the embankment, and the flood-water flowing over it discharges itself through a rock-cutting, and is led for some distance into the valley below.

The arrangement finally adopted for withdrawing water from the enlarged reservoir was a syphon discharge-pipe, laid over the top of the old embankment and face-wall, but below the level of the new portion of the work. The syphon starts from the bottom of a straining and regulating tower built inside the reservoir, 30 feet distant from the front of the old masonry sluice, and terminates in a valve-house situated at the foot of the outer slope of the embankment. This expedient was employed as the expense of constructing a tunnel outlet in the natural ground round the end of the embankment, owing to the conformation of the valley, would have been great, and it was not considered advisable to interfere with or break through the continuity of the old face-work by carrying a discharge pipe through or below it.

The regulating tower, situated at the toe of the new slope inside the reservoir, was founded on the solid rock 12 feet below the old bed, and its internal dimensions are 15 by 6 feet. The outer wall of the tower has three openings at different levels, each 2 feet square, covered by iron sluices or vertically sliding doors, each protected by wire-netting and worked by a screw-gearing placed on the upper floor of the tower. By opening the sluice-door nearest the surface of the water, the latter is admitted into a straining chamber and passes through a set of copper wire-gauze strainers, having 30 meshes to the inch, before reaching the mouth of the syphon discharge-pipe. A valve commanding the entrance to the syphon pipe is also worked from the upper platform of the tower; which latter is covered in overhead, and is connected with the top of the embankment by a light wrought-iron footbridge. The nearest foundation of the water-tower is connected with the masonry

of the old native discharge sluice by a half-arch, so constructed as to carry the ascending portion of the syphon pipe. The latter is 2 feet in diameter and 184 feet long. It is supported throughout its length on masonry blocks and concrete, everywhere founded so as to be secure against any possible subsidence, especially where the syphon pipe is carried through the puddle-trench. The summit or crest of the syphon passes through a charging well, inside which, and connected with the syphon, is a vertical charging pipe 4 inches in diameter, having a funnel mouthpiece, through which the syphon is filled with water, after closing the terminal valves at each extremity of the main pipe. At its outer and lower end the discharge syphon terminates in a valve-house at the foot of the embankment. It is here turned upwards and carries an 8-inch air-valve, by means of which air from the main is prevented from entering the syphon. A branch pipe at right angles to the upturned end of the syphon is furnished with two 15-inch valves—one of which controls the entrance into the main supply-pipe leading to the city; the other opens or closes a short scouring outlet, by means of which the syphon and the bottom of the straining tower can be cleared out, or through which any available surplus storage water can be given out for irrigation below the reservoir.

The lift, or height of the syphon, from the bottom of the lowest sluice-door in the tower to its crest in the charging-well is 14·55 feet, but it is not contemplated to withdraw the water in the reservoir lower than 5 feet above that level, so that the working lift is not more than 9·55 feet, at which level the valves at the outer end of the syphon would be 5·2 feet below the water surface. The main pipe to the city is 13 inches in diameter, and four miles long. In addition, 10,500 yards or six miles of distribution pipes of various sizes were provided. These pipes work at an average head at lowest water of from 30 to 60 feet. The city service is for the most part a public one on the ground level, as common in India; the water being supplied from self-closing standards placed at frequent intervals along the public thoroughfares. Fire-cock air-valves are also provided at every 100 yards.

The new and enlarged Ambajhari reservoir, as completed in

1873, contained $257\frac{1}{2}$ millions of cubic feet of water, with an available storage of 240 millions, calculated to supply the greater portion of the native city of Nagpur with 15 gallons per head per day of 24 hours, during years of minimum rainfall. The completed cost of the project, including all incidental charges and the distribution service as initially contemplated, was approximately £40,000, or at the rate of 9s. 5d. per head of population supplied.

The water-supply scheme as above outlined provided for the wants of the larger portion of the native city of Nagpur; but some of the higher parts of the town, together with the whole of the adjoining civil station, containing a numerous and increasing population, was not commanded by it; still remaining entirely dependent upon subsoil wells. After a severe outbreak of cholera in the year 1887, largely due to the scarcity of water attending the failure of these wells, an extension of the water-supply to those areas situated at too high a level to be supplied by gravitation from the reservoir was determined upon, and a project was drawn up for raising the additional water required for the higher levels by means of pumping.

The calculations undertaken showed that, including a liberal supply for the service of the Bengal-Nagpur Railway Company, the total daily requirements for the proposed high-level extension was 438,400 gallons, or 70,144 cubic feet, equivalent to a supply of 21 millions of cubic feet in 300 days, which was taken as the largest interval of continuous drought. This requirement it was estimated could be met from the existent Ambajhari reservoir; but, to allow for the natural increase of consumption in the city, and still to retain the lowest water level at the limit originally considered advisable, it was determined to slightly increase the storage capacity of the reservoir by raising the crest of the waste-weir one foot, in order to impound an additional 15 millions of cubic feet of water—a demand which it was shown the drainage area of the reservoir and the average monsoon rainfall could amply meet.

Under the new scheme, which was carried out and opened for service in the year 1890, the level of the original waste-weir was raised 12 inches, and its length was at the same time increased from 200 feet to 457 feet, so as to greatly increase

its discharge under a more limited head. The water for the high service was drawn from the original 13-inch city main, at a point situated $2\frac{1}{2}$ miles from the reservoir. Here a 13-inch branch pipe 735 feet long was connected, to convey the water to a large covered underground cistern, holding about a day and a half's supply. From this cistern it is pumped by powerful steam-pumps into a covered service-reservoir, situated on high ground at a distance of one and a half miles, from whence it is distributed over the new area by gravitation.

The pumping cistern or reservoir measures 150 feet by 40 feet, and provides for a full water depth of 17 feet 3 inches, and an available capacity of 95,000 cubic feet. The pipe or 'rising main,' 8000 feet long, through which the water is pumped to the high service-reservoir is 8 inches in diameter. The high-service reservoir itself is divided into two compartments, each measuring 75 feet by 40 feet by 16 feet. It has an available capacity of 82,500 cubic feet, and a level $70\frac{1}{2}$ feet above the crest of the weir at Ambajhari.

The utilisation of two and a half miles of the original 13-inch main for the new scheme was decided upon, after full consideration, solely from motives of economy; but it having been found that the pressure in the city in the hottest months is inconveniently affected, the municipality have since determined to incur the extra expense of a separate and independent 12-inch main from Ambajhari to the pumping reservoir. Thirteen miles of additional distribution pipes were required for the new high-service extension. These work under a minimum effective head of 13 feet, but an average effective head of 35 feet in the civil station and 24 feet in the city. The extension provides for the daily wants of 44,000 persons, at an estimated outlay of three lakhs of rupees.[1]

[1] The data for the above outline of the Nagpur Waterworks, and the subsequent high level extension, is derived from vols. xxxix. and cx. of the *Min. of Proc. of the Institution of Civil Engineers.*

CHAPTER IV

LAHORE AND KARACHI

Lahore Waterworks—Situation of Lahore and population—Aspect of the city—Project for waterworks and drainage—Main features of the water-supply as carried out—Quantity of water—The supply-wells in the bed of the Ravi—The pumping-well—The service-reservoir—Particulars of the distribution—Failure of the service-reservoir—Intermediate arrangements—Rates charged for water—Karachi Waterworks—Peculiarity of scheme—Necessity for improved water-supply—Proposals made—Project as finally decided on—The Malir river—The supply-wells—Excavation of wells without pumping—The masonry conduit—Pipe and masonry syphons—The valve-house and service-reservoir—The distribution—Cost and success of the Karachi Waterworks.

Lahore Waterworks 1877 *to* 1881.

LAHORE, the capital of the Panjab, is a very ancient walled city standing on the alluvial plain formed by the Ravi, a river now passing about two miles to the north of the town, but formerly running close under its walls. Like all ancient cities on the plains of India, the accumulating *débris* of centuries has gradually and irregularly raised its area somewhat above the level of the surrounding country. The highest portion of the elevation in the case of Lahore, and marking probably its oldest seat, consists of a ridge running east and west on its northern side. The city walls form a parallelogram, enclosing a densely populated area of about 461 acres; the suburbs of the town having in recent times rapidly extended themselves outside the walls in every direction except to the northwards.

The total population within the walls, by the census of 1871, was about 92,000, and in the suburbs 36,000, giving a total population of about 128,000 persons. The only source of water-supply for this population was that derived from wells situated within the densely crowded city area, and sunk into a subsoil saturated

with the filth of ages; yielding a water totally unfit for human consumption. The high and excessive death-rate of Lahore, which for so long naturally attended this condition of the water-supply, at length aroused the action of the authorities, and various proposals for improving it, as well as for the introduction of an efficient system of sewage drainage, were made and discussed, until in the early part of the year 1877 the existing water-supply scheme, which has been in operation since the 30th June 1881, was at length approved, and the municipal loan requisite for its construction was granted by the Government of India. The aspect of the city at this time is found thus officially recorded: 'The streets and lanes in the city of Lahore are peculiar, to say the least of it. If there ever has been an idea of alignment it has been lost sight of long ago, and at the commencement of the works they might nearly all be described as mere passages and water-courses, winding about in a most tortuous fashion, liquid sewage and storm water having been for a long time the only engineers, and sun and rain almost their only sanitary conservators. It is only lately that a cart could get into many of the streets, and where it did get in, the difficulty was to get it out again.'

'It had long been the desire of various civil officers connected with Lahore to ameliorate in some degree this state of matters, and to open out the city and widen some of the streets. It was, however, found impossible to alter their alignment, as they were the natural drainage courses of the city, the roads having their levels well below the sites on which the houses were built. When the water-supply and sewage-drainage schemes were being designed, the widening of some of the principal streets was considered one of the objects to be held in view. There were, however, many difficulties to contend against; amongst the greatest being the prejudice of the inhabitants against any attempt to alter the existing state of things—by far the most serious, however, was the question of taking up land in the streets. The houses were huddled close together, and each house occupied a very small base area, although built many stories high; and in any street improvement requiring widening, the great number of tenements to be taken up, and the many inhabitants thus left houseless, became a serious

consideration. The Government and the municipality, however, recognised the fact that the introduction of water-supply and of drainage schemes made it imperative to do something towards widening the streets; it was in fact compulsory to make a re-alignment where the principal mains had to be laid. To avoid taking up more land than was absolutely necessary it was decided to re-align that side of the street only on which the pipes would be laid, and this was adhered to.'

The main features of the water-supply scheme actually carried out at Lahore are the following: The supply of water is taken from wells sunk, practically speaking, in the bed of the Ravi river, from which it is lifted by pumps into a service reservoir placed at such a height that every part of the city and suburbs are supplied with pure water under a head of pressure; the distribution being by means of cast-iron mains and service-pipes. On the northern side of Lahore, in the form of a horseshoe, extends the plain of the Ravi. It is well known that the valleys through which the Panjab rivers flow afford a constant and never-failing supply of water. Below their surface run, in fact, clear and sparkling underground rivers, whose flow is continuous and inexhaustible at all seasons, and it is this underground Ravi that has been laid under contribution for the water-supply of Lahore. The northern plain, selected as the most favourable and convenient position for the supply-wells, was practically virgin soil, free from all organic impurities, and as during heavy freshets it is liable to be flooded by the river, there was no probability of the city ever being extended on that side.

The quantity of water required for the daily service of the city population, taken at 130,000, was 1,300,000 gallons, or 208,000 cubic feet, at the fixed rate of 10 gallons per head in twenty-four hours, and from the result of some experimental trials made on the site selected for the wells, it was estimated that a series of six—afterwards reduced to four—connected wells, each 20 feet in internal diameter, sunk to a depth of 32 feet, and placed 300 feet apart, would yield this supply, as well as a surplus quantity ample for the city demands for some time to come; a supply, moreover, which could at any time be augmented by sinking additional wells.

As the current of the underground river flows from east to west, the wells are placed in a straight line north and south, at right angles to the stream. On the up-stream side of the line of supply-wells two rows of 16-inch pipes, 3 feet 6 inches apart—placed at a depth below the lowest limit of pumping—connects the wells with each other, and with the sumph, or pump-well, by means of 12-inch connecting pipes; joined and controlled by valves in such a manner that the supply of water from each can be carried into the pumping-well independently. To the connecting pipe inside each supply-well is fixed a vertical pipe, also 12 inches in diameter, provided with horizontal arms for drawing off the water, at either 10 or 20 feet below the normal water level. On each of these arms a valve is fitted, worked from above by a screw-down rod, by means of which the water can be either cut off from one or other of the arms, or the supply from any one well can be completely cut off. The connecting pipes are carried through a continuous line of trench-wells, each 7 feet square, running parallel with the line of supply-wells, all being provided with large openings through their sides for the passage of the pipes, which are supported on the well curbs. The cavities at the bottom of the trench-wells are filled up with broken bricks, so that the pipes rest on a firm foundation throughout. After the pipes were laid the masonry of the small wells was brought up to a level of 3 feet above the water-line, and the whole line was then arched over and filled in to ground level; manhole doors being left at 50 feet intervals to facilitate future inspection of the piping.

The sumph, or pumping-well, is 15 feet in internal diameter, and is situated on the line of supply-pipes at a distance of 65 feet from the first supply-well. It is completely closed at the bottom with solid blocks of masonry, the joints of which are filled in with hard-wood wedges to prevent the entry of water, which might disturb the sandy soil when the pumps are at work. The bottom of the well is 32 feet below water-level, and the pumping is effected by two horizontal condensing engines with double acting bucket and plunger pumps, each capable of raising 1,300,000 gallons of water in twelve hours to a height of 150 lineal feet, and forcing this quantity through a 20-inch main, 3200 feet in length, when working at forty revolutions a minute.

The service-reservoir, 265 feet in length and 150 feet in width, divided into two compartments by a division wall, was constructed on a site selected on the highest part of the city ridge. Its capacity was calculated for a two days' supply, when full to a depth of 11 feet 6 inches. The ridge within the city on which the reservoir is erected, was the only site sufficiently high to allow the water to be delivered under an average head of about 40 feet of pressure throughout the main distribution. There were, however, some elevated portions of the same ridge where the pressure would only admit of a street service, but as it was deemed desirable that the houses in the highest parts should be supplied, as well as an efficient fire-service, three stand-pipes were erected on the north side of the reservoir, of sufficient height, when water was passed over them, to effect the object desired. This high service is capable of exerting a pressure on the mains and service pipes of 50 feet over the highest water-level in the reservoir, or a total pressure of about 90 feet.

The city area supplied was divided into five separate districts, each having its own main, and system of street service-piping, supplied directly from the reservoir, or high service stand-pipes. The service pipes of each district are, however, connected with the main pipe of the adjoining system, so that in case of a stoppage of one main, the pipes can be supplied from another by opening the necessary connections and closing the stopped main. By this means also the water can be confined to any one or more districts; it can be made to circulate freely throughout the entire system, and thereby establish a better equilibrium of pressure, or in case of any abnormal demand in one district, the adjoining mains can give it an auxiliary supply. Altogether nearly twenty-two miles of main and service piping, varying from 20 inches to 3 inches in diameter were initially provided. Provision is everywhere made for direct communication between the street service pipes and the houses, into which water is delivered whenever desired, in preference to drawing the supply from the street stand-posts, of which 300 were originally erected at convenient intervals. One hundred and eighty street fire-hydrants of 2 inches diameter, were also furnished at convenient sites, so as

to be available in cases of fire, as well as for sanitary purposes. The pipe laying was a work of great difficulty, requiring great care, owing to the narrow and tortuous nature of the streets and lanes, and to the bad soil.

Soon after the first opening of the Lahore Waterworks a settlement in the foundations of the service-reservoir occurred, which compelled its disuse until a new reservoir could be built. In the interval, arrangements were made to carry on an intermittent supply system by making use of the high service stand-pipes; provision being made for the overflow by a special outlet, instead of allowing it to pass through the reservoir. In order to avoid the needless expense of pumping the whole water to an unnecessary elevation, the height of the stand pipes, was, as a temporary measure, reduced to nearly the same level as the ordinary pressure of the disabled reservoir. The new service-reservoir on the original site was completed in the year 1883, and has been entirely successful. It consists of four large iron tanks, each 60 feet by 60 feet by 12 feet containing a supply of a million gallons.

The rates charged by the municipality are 8 annas per 1000 gallons when supplied retail, and 6 annas for manufacturing purposes. It is satisfactory to find it recorded that 'any caste prejudices against using the water has long since broken down, and the people fully appreciate the pure water, with as genuine a feeling of satisfaction as those who are considered more advanced in civilisation.' The total initial cost of the Lahore water-supply project, as above sketched, is given as rupees 15,00,935 or £150,093 at par.

Karachi Waterworks, 1880 *to* 1884.

The peculiarity of a gravitation scheme of water-supply derived directly, and without intermediate pumping from wells, is met with in the case of the sea-coast town of Karachi, the capital of the Province of Scinde. The works in connection with this scheme were commenced early in the year 1880, and were brought to completion in 1884, having been partially opened in 1883. The necessity, on sanitary grounds, for an improved water-supply for the rapidly rising commercial town

of Karachi, had already for many years been admitted, and several proposals for its improvement had been made and rejected on various grounds, when, in the year 1868, careful experimental trials were made to ascertain by means of pumping: at what level 1200 gallons of water per minute could be obtained from the underground flow of the Malir river. The experiments made proved that the above quantity of water—which was that necessary to supply the town of Karachi with twenty-two gallons per head per day for a population of 80,000 inhabitants—could easily be obtained at no great depth. A project was accordingly elaborated for supplying the town with water to be derived from wells sunk on the banks of the Malir river, and carried across the intervening country by means of a main of cast-iron pipes, to a reservoir to be built near the town. The total estimated cost of this project was £152,000. Owing, however, to a great rise in the price of iron in England occurring before the works were put in hand, the scheme was indefinitely postponed, the money at the command of the municipality not being sufficient to meet the increased outlay.

In the year 1873, the question of the water-supply was again taken up, and in order to reduce its initial cost—the price of iron being still high—it was proposed, in view of the cheapness and excellence of the stone available in the neighbourhood of Karachi, to substitute a masonry conduit, built underground, in place of a cast-iron main. A new scheme, embodying this substitution, estimated to cost £120,000, was prepared, but the available means of the municipality—without recourse to a loan, which was not desired—being limited to about £85,000, the cost of the project was further reduced to that amount, by a curtailment of the distribution system. On the completion of the reduced scheme, however, the public appreciation of the pure water, and the demand for it at remunerative rates was so great, that the municipality at once applied for, and were accorded permission to raise a loan for the execution of the curtailed portion of the project, which was then carried out with little or no delay.

The Malir river, which rises in the mountainous district between Karachi and Sehwen, drains a sparsely populated

country about 600 square miles in extent. At the point selected for the supply-wells, it is about 2100 feet wide, and when in flood it discharges a vast body of water. For the greater part of the year, however, the bed of the river is perfectly dry, but water is everywhere to be found by digging a few feet below the surface of the sand. About 1000 feet from the near bank of the Malir, which is well defined, two wells, each 40 feet in internal diameter, 36 feet deep and 400 feet apart, were sunk. These wells supply by gravity, through a conduit over 18 miles in length, and principally constructed in masonry, a service-reservoir situated close to the town of Karachi. From the service-reservoir and inlet-well in connection with it, water is delivered by gravitation to all parts of the town, port, civil lines, and military cantonment, through cast-iron pipes; numerous public street services being also established. The two supply-wells were excavated to their full depth of 36 feet without the aid of pumps of any kind. About 3 miles from the Malir, the line of conduit crosses a smaller river called the Thudda, and as the bed of this stream, at the point of crossing was at a lower level than the bottom of the wells, the excavation of the trench for the conduit was commenced at this point, and carried onwards to the site of the wells. By this means all the water found, both in the conduit-trench and the wells, was drained off into the Thudda. An enormous extra expense in pumping was saved by the possibility of this expedient, as it was found that for a period extending over many months, the volume of water drained through the conduit-trench excavation amounted to two million gallons of water per day. As soon as the excavation of the conduit-trench and the two wells was completed, the latter were 'steined' or lined with masonry 3 feet thick, consisting of large blocks of stone, laid dry; the joints being everywhere left rough and open, so as freely to admit water. Above water-level the lining-wall is set in mortar, and is carried to a height of 23 feet above ground-level; the work being finished off with an ashlar cornice and coping.

In the centre of each well—on a secure foundation—is erected a cast-iron valve-shaft, 4 feet in diameter, provided with three sliding sluice-doors, worked from an upper platform, through which water is admitted into the shaft at different

levels. Near the bottom of the valve-shaft a 24-inch main pipe, fitted with a regulating valve (also worked from the upper platform) issues, and connects the valve-shaft with a junction tank or chamber 22 feet deep, and 10 feet in diameter, situated nearly a mile from the Malir wells. At this junction tank the masonry conduit commences.

The masonry conduit, including the length of several cast-iron pipe-syphons, constructed to pass the water under the natural streams intersected in its alignment, is over $17\frac{1}{2}$ miles long. For the first $10\frac{1}{2}$ miles of its course from the junction tank its internal section is 3 feet 3 inches wide and 3 feet high, with a fall of 2 feet per mile; for the remaining part of the length the internal section is 2 feet 6 inches wide and 2 feet 3 inches high, the fall varying from 3·9 to 9 feet per mile. From the level of the bottom of the 24-inch pipe issuing from the valve-shaft in the supply-well, to the bottom of the masonry conduit at the first point where it terminates in the inlet-well, adjoining the service reservoir, the total vertical fall is 69·02 feet. The conduit is built of rubble masonry coated on the inside with Portland cement plaster half an inch thick. The top is slabbed over with stone 8 inches in thickness, over which is laid a covering of concrete, any remaining depth of the trench being filled in with soil.

Along the course of the conduit, the water is passed under five intervening *nalas* or streams, by three pipe and two masonry syphons, the largest being the pipe-syphon carried under the Thudda river. Ventilating shafts, 5 feet by $2\frac{1}{2}$ feet in section, are provided at intervals of $\frac{1}{2}$ a mile to 1 mile apart, foot-irons being fixed in each shaft to enable an inspection of the conduit to be made when desired. The water is discharged by the masonry conduit into an inlet-well, 20 feet in diameter, which, together with the valve-house, is built adjoining the service-reservoir, and acts as a second chamber to it. The walls of the inlet-well are carried up to a height of 24 feet above ground level, and carry a concrete roof and an ashlar battlemented cornice. The distributing or service-reservoir is 200 feet long and 150 feet wide, and contains a maximum depth of water of 10 feet 9 inches. The total capacity is nearly 2 million gallons. The reservoir is built in excavation, and is

roofed over with rubble masonry, concrete, and earth, supported on lines of archwork. A partition wall runs for nearly the whole length of the reservoir, and separates the inlet-pipe from the main delivery-pipe, thus ensuring a complete circulation of the water. The water-level in the reservoir is 55 feet above the average ground floor-level of the houses in the native town.

A cast-iron inlet-pipe, 24 inches in diameter, controlled by a valve at the well-end, connects the inlet-well with the reservoir, where it terminates in a bell mouth. The main delivery-pipe, also 24 inches in diameter, has two branches, leading, one from the inlet-well, and one from the reservoir. These are fitted near each inner end, with 24-inch sluice-valves, so that water can be supplied to the town direct, either from the inlet-well or from the reservoir, as occasion may require. A cleansing or scouring-pipe, which communicates with a built drain, is laid 2 feet below the level of the main delivery-pipe, and, like it, has one branch from the well and one from the reservoir, ending in each case with a sluice-valve.

The distribution throughout the town, port, civil lines and military cantonment of Karachi, is effected through main and service-pipes of cast-iron, varying from 24 inches to 2½ inches in diameter, having an aggregate original length of nearly 32 miles (now probably much more). A 5-inch pipe was laid down for the special supply of the main railway station, and a 6-inch pipe was carried to Keamari, a distance of over 5 miles from the civil lines, for the supply of the shipping and engine-house at Merewether pier. In the town, hydrants are placed, at intervals of 200 feet in the principal thoroughfares, to facilitate street-watering, and in other streets at 400 feet intervals. A neat and ornamental pattern of *bhisti* (*i.e.* water-carrier) service, delivering water from overhead, as well as a roofed-in public street service, each containing twelve self-acting bib cocks and drinking-trough for cattle, is adopted at Karachi. Of these forty, and twenty-eight, respectively, were originally provided, distributed over the more thickly-populated parts of the town.

The total cost of the Karachi Waterworks, as completed in 1883, amounted to nearly £115,000, and the maximum possible

also contaminated by the neighbourhood of small tanks fed by the surface-drainage of the streets; for many years, therefore, an improved water-supply for Jubbulpore was a most urgent want.

The history of the scheme carried out in the years 1881-84 may be shortly told. As far back as 1872, a special engineer was deputed by Government to examine and report upon the available sites—within a reasonable distance of the city—offering facilities for the storage of water. A number of sites were at that time reported on; but all proved in one way or another unsuitable. In the following year, the Government engineer then attached to the Jubbulpore Division, was instructed to make proposals for a water-supply scheme, and he shortly afterwards submitted sketches of two projects to supply the city by gravitation.

Of these proposals, one was rejected owing to the very limited head of water available. The remaining scheme, which formed the basis of that afterwards carried out, was to construct a reservoir on the Khandari nulla, at a favourable site situated about 7 miles from the city, and convey the water the whole distance by means of pipes. The head of water in this scheme was sufficient to command at good pressure all parts of the native city and cantonments; but its estimated cost amounted to five lakhs of Rs., or £50,000 nominal, and the finances of the municipality would not admit of so heavy an outlay. The scheme was, therefore, in abeyance for some years. The privations undergone by the city population in consequence of the deficient rainfall of 1878 were so great, that the improved water-supply scheme, and especially the means by which the necessary money could be raised, was earnestly taken up by the local civil officers, with the result that arrangements were shortly afterwards entered into with a local firm of wealthy bankers, through whom the funds were obtained on fairly easy terms. It is owing to the public spirit and liberality of this firm that Jubbulpore is in great measure indebted for the excellent water-supply which it has now enjoyed for more than a decade.

The question of funds having been satisfactorily settled, the necessary surveys and studies for the proposed water-works

were commenced towards the end of the year 1879, and a detailed project was elaborated. The new census of the early part of the year 1881, however, showed so considerable an increase of population that a revision of the project as originally prepared became necessary, and the details of an enlarged scheme, providing for the supply of 100,000 persons, were rapidly drawn up. This scheme was sanctioned by Government towards the end of the same year. Preliminary work had, however, been commenced early in 1881, enabling the construction of the reservoir dam to be put in hand before the close of the year. From this time operations were carried on vigorously up to the beginning of the year 1883, when the works were formally opened, with some ceremony, by the Chief Commissioner of the Central Provinces on the 26th February, although it was not until about a year later that the full scheme was entirely completed.

The preliminary operations, commenced in April 1881, comprised excavations for the foundations of the masonry dam of the intended reservoir; the construction of service-roads, and accommodation for the supervising establishment and for the work-people. Owing to the great scarcity of water during the hot season, provision was made for the temporary storage of a certain supply by the construction of a small tank within the reservoir area. The important matter of conservancy was also attended to, and so efficient were the arrangements made to preserve the coolie lines in good sanitary condition, that notwithstanding the small army of labourers—numbering nearly 3000 persons, which was collected at the site—no epidemic occurred during the entire progress of the works. The quarrying of the necessary stone for the main works, and the provision of the other various materials, as well as plant, required, was rapidly pushed forward, so that by the month of December 1881 the construction of the masonry dam could be commenced. The site for the dam was chosen at a point on the Khandari nulla, situated about 8 miles east of Jubbulpore, at an elevation of 1390 feet above mean sea level. The foundation material met with along the whole alignment of the dam was of a most favourable character; a good description of basalt rock being everywhere found at moderate depths.

Excellent basalt stone for building purposes was also procurable close at hand, so that the site offered great natural advantages for the construction of a masonry dam.

The dam, as constructed, is 1680 feet long, and has a maximum height of 71¼ feet above foundations. The maximum thickness is 52 feet at the bottom, and it is everywhere 9 feet thick at the top; the finished structure containing about 1,111,200 cubic feet, or 41,155 cubic yards of rubble masonry, with about 53,000 cubic feet, or 1963 cubic yards, of concrete in foundations. For the whole length of the dam a trench, 3 feet broad and from 3 to 2 feet in depth, below the general level of the foundations, was cut into the rock, and filled with concrete, and wherever faults or fissures were encountered, these were carefully and completely opened out, until firm rock was reached, the void spaces being filled in with concrete. Thus the work was everywhere rooted into a solid and impervious strata, and rendered perfectly secure against all leakage along the line of junction.

A flood-escape, 300 feet long, with cill, or crest, placed at the top level of the stored water, or 61¼ feet above the lowest bottom of the reservoir, is provided on the right flank of the dam. Immediately adjoining this—which may be called the normal escape-weir—an additional length of escape, 437 feet long, is placed, having its cill 3 feet higher, whilst in continuation of the latter a further length of 628 feet has the cill level 4 feet above the normal escape; the remaining flank of the dam, 315 feet in length, being 5 feet above the same level. The combined discharging power of the escapes is estimated at 18,450 cubic feet per second: this is equivalent to a rainfall of 5·44 inches in an hour over the whole catchment of 5¼ square miles, reaching the escape at a uniform rate in the hour. The water is discharged directly on to the solid basalt rock below the dam, without the intervention of steps, or precautions of any kind; the height of the fall at the normal escape being 23 feet. On the left of this escape, a long guard wall, 326 feet in total length, cuts off the water from access to the lower part of the valley, and a short guard-wall, 80 feet in length, affords protection to the base of the hill on the right flank of the dam. These guard-walls are set well back from the extremities of the

escape, so as to be clear of the falling water. The crest of the escape-weir is protected with ordinary concrete, finished off with 2 inches in thickness of fine Portland cement concrete, instead of with cut stone.

A solidly built masonry water-tower, securely founded on the solid rock, is constructed at a distance of 10 feet from the inner or reservoir face of the masonry dam, and is connected with the top of the dam by a flight of steps carried by an arch. The tower is circular in plan, with an octagonal covered-in chamber at the summit. It has an internal diameter at bottom of 6 feet, and an external diameter throughout of 18 feet. At the top, the internal diameter is 11 feet, and the height of the tower from bottom of foundations to the battlemented summit of the octagonal chamber is 87½ feet. Attached to the outside face of the tower is built a rectangular chamber, 10 feet by 6 in plan, carried up from the floor level (which is 10 feet above the lowest bottom of the reservoir) to a short distance above high-flood level. Into this chamber the water of the reservoir is admitted through a set of wire-gauze strainers, having forty meshes to the inch. There are two sets of these strainers, placed a short distance apart, and fixed in wooden frames, which work in grooves provided in the outer wall of the strained-water chamber, and either set can be hauled up for cleaning or repair, by special tackle fixed above for the purpose. The object of these strainers is to prevent fish or any solid matter from the reservoir entering the pipes.

From the strained-water chamber the water passes into a vertical stand-pipe, fixed inside the water-tower, through three radiating inlet pipes, which are carried through the intervening wall at three different levels. The entrance of water is controlled by valves placed on the inlet-pipes near their junction with the stand-pipe inside the tower, where they are at all times accessible. The outer ends of the inlet-pipes inside the strained-water chamber are turned upwards, and are bell-mouthed, so that whenever repairs to the inside valves are required, the outer ends of the pipes can be closed by a ball of wood, or other stopper of proper diameter. A small pipe, provided with a stop-cock, connects the interior of each inlet-pipe with the outside water, so that when it is desired to remove

the stopper, the pressure can be equalised by the admission of water below it. In addition to the three inlet-pipes, a fourth pipe placed on the bottom floor of the tower, passes from it through the strained-water chamber into the reservoir, terminating in a hinged flap-valve worked from above. The pipe, which is provided with a large valve in the interior of the strained-water chamber (worked also from the top floor), and with an ordinary screw-down valve inside the tower—is called the 'scouring-pipe,' and its object is to remove any sediment which may collect in front of, and inside, the strained-water chamber, which is done by the scouring action set up when the valves are opened. The vertical stand-pipe within the tower is connected with the main supply-pipe, and this, together with the scouring-pipe, both pass from the bottom of the tower hrough a culvert, which is carried underneath the dam. The scouring-pipe ends at a short distance beyond the outer toe of the dam, and the main supply-pipe, 16 inches in diameter, carries the water to the town of Jubbulpore. No arrangements are required for filtering the water, but special precautions are taken to prevent any fouling of the catchment area of the reservoir.

The 16-inch main pipe between the reservoir and the town is provided with frequent stop-valves, and on all the pipe systems air-valves on the summits, and scour-valves in the depressions are fixed. The pipe system conveys water to all parts of the native city, where it is supplied free at all the numerous public standards. A supply is also furnished to the cantonments and civil station, to the central jail, railway station, and other public buildings, as well as to private houses at agreed rates.

The total original cost of the project amounted to 6,91,140 rupees, or £69,114 at par of exchange. It was arranged that the money borrowed for the construction of the works should be repaid in a period of twenty-two years, the yearly instalments to be met from the annual income of the municipality. As actually carried out, the Jubbulpore waterworks are designed to supply 88,423 persons at the rate of 15 gallons per head per day of twenty-four hours, or nearly 59½ millions of cubic feet per annum, which is reckoned, exclusive of the

monsoon, at 280 days. The full capacity of the reservoir up to the level of the normal escape-weir is 203 millions of cubic feet. The thickness of the masonry dam, moreover, has been made so as to allow an extra height of 3¾ feet being added whenever it may become necessary to increase the storage capacity. By thus raising the dam, additional water, to the amount of 36 millions of cubic feet, can be stored. In estimating the quantity available for the wants of the city, the bottom 10 feet in depth of the reservoir, which amounts to 548,413 cubic feet, is neglected, this space being left for deposit of silt. A vertical depth of 6 feet, taken on a mean area of the stored water, and amounting to about 47½ million cubic feet, is also allowed for evaporation and absorption. These volumes added to the calculated yearly draw-off from the reservoir of 59½ million cubic feet, amount in all to 107⅓ millions of cubic feet of water. The available annual flow from the catchment basin of the reservoir, calculated on the lowest observed rainfall during a period of thirty-five years, is taken at 119½ millions of cubic feet, giving a lowest surplus volume of over 12 millions. In average years the quantity available for storage is of course much greater, and it is calculated that the reservoir will practically store sufficient water to meet the requirements of two consecutive seasons without replenishment.

The foregoing examples of town water-supply schemes in India, include among them some of the largest of these undertakings which have been carried out in that country; they have, however, been partly selected from the large total of such works, with a special view to illustrate distinct types and varieties of construction, one or other of which, merely modified in size and detail according to local necessities and conditions, will be almost certainly found repeated in the majority of the remaining works of this class, which of late years have been called into existence by so many municipalities throughout the country, but which it will be unnecessary for the purposes of this volume to further particularise. The gradual loosening of caste prejudices, and the growing public appreciation of the practical benefits and advantages derived from a pure and unfailing water-supply, is now sufficiently apparent, and for many years to come the provision of an adequate supply of whole-

some water to the town populations of India, must everywhere be one of the chief concerns of the urban authorities. That a vast number of such works urgently call for construction does not require assertion, nevertheless no inconsiderable progress has already been made. Besides the particular works which we have arbitrarily selected as illustrative examples, water-supply schemes of considerable importance have been carried out at Burdwan, Dacca, Mhow, Poona and Kirkee, Satara, Jalgaon, Maraj, Pandapur, Thana, Kolapur, Secunderabad, Bangalore, Ootacamund, Wellington, and Hyderabad in Scinde, as well as in the case of a large number of the smaller towns throughout the country.

Projects for the water-supply of most of the larger cities of the North-west Provinces—such as Lucknow, Cawnpore, and Benares, are either in active construction, or under preparation. In the case of Lucknow, the great necessity for introducing a supply of pure drinking-water, has occupied the serious attention of the Government and Municipality for many years. In the year 1881, a special engineer officer was appointed to report on the subject, and after some discussion it was determined to sink an Artesian well. The boring was commenced in the year 1889, and by May of the year 1890 had reached a depth of 1336 feet, at a cost of 93,000 rupees (£9300 at par) without result. The boring was then abandoned, and it was decided to adopt a scheme for the supply of water by pumping, and the formal inauguration of this project—by the Lieutenant-Governor of the North-west Provinces—took place in November 1892.

The main features of the new Lucknow water-supply are, an intake pumping station at a spot above the city on the right bank of Nagaria Nala: a service-reservoir, with settling-tanks, filtering beds, etc., and a distribution of the filtered water through thirty-three miles of iron piping, and 351 standposts in the native city and civil lines, and through nineteen miles of piping and 100 standposts in the military cantonment. The scheme is calculated to supply two million gallons of pure drinking-water per diem to the population of the native city and civil lines, and 200,000 gallons to the cantonment; the estimated capital outlay amounting to 15½ lakhs of rupees

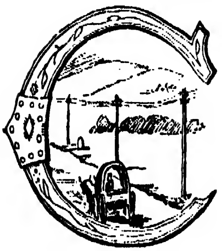
(£155,000) with an annual expenditure of 1,40,000 rupees (£14,000) in interest and cost of maintenance.

On November 4th, 1892, a water-supply scheme for the capital city of Delhi, which was begun in the year 1890, was formally opened for the public service. A reservoir 300 feet long and 150 feet wide has been constructed on the highest part of the famous ridge, close to the city, and a supply of ten gallons per head per day for a population of 173,000 persons in the city, fort, and cantonments has been provided for. In numerous other parts of India water-supply projects are being mooted, or are in active prosecution, and everywhere a practical recognition of the immense value of this special class of public works, so necessary to all real progress in sanitation and civilisation, can be noted as one of the most wholesome and valuable products of the comparatively recent development and progress of municipal institutions in India.

THE ELECTRIC TELEGRAPH IN INDIA

THE ELECTRIC TELEGRAPH

Introductory observations—Electric telegraph apparatus—Varieties of signals—Origin of the electric telegraph—Outline of early history of the invention—Statical electrical apparatus—Dynamic electricity—Deflection of magnetic needle—Wheatstone and Cook—First telegraph line in England—First experimental line in India—Dr. O'Shaughnessy—India a pioneer in electric telegraphy—Telegraphic communication between England and India—Statistical details of modern electric telegraphs in India—Extent of the system—Capital outlay—Revenue—Number of messages—Establishments—Classifications and working—Concluding observations.



COMMUNICATION by means of the electric telegraph is a practically indispensable adjunct to the effectual and safe working of railways, and it was principally, in rapid correspondence with early railway necessities, that this exceedingly useful invention assumed a practical and workable shape. In every civilised country in the world, the electric telegraph is now so common and familiar an agent, and its use, and numberless public and private conveniences,—altogether apart from railway service—forms so integral a part of all civilised life in modern times, that it has become difficult to realise that its practical use extends only over a single half century. It is unnecessary here to enter into any detailed description of the essential principles of an invention so well known, and in its main features so familiar to every section of the community. It will suffice to say that, proceeding upon the principle that an electro-magnetic current can pass along a conducting wire to a great distance, and can be made to move a magnetic needle at any point of its course—signals—according to any established code, can be readily conveyed,

with almost incredible speed from one end of a wire to another; the signals being sufficiently varied to express letters of the alphabet and the ten numerals, or particular combinations of letters, words, or phrases, so that communications can be made at any one place, and can be read off at another, even although many hundreds of miles apart.

The apparatus of an ordinary aërial electric telegraph consists of a line of conducting wire, or wires, of galvanised iron, suspended on earthenware tubes or 'insulators,' carried on poles which are spaced at certain distances apart from station to station. A single wire will serve for one circle of the electric current; it being found that the earth itself is a conductor, so that if a current pass along a wire above ground, it will return through the earth, provided the wire at each end is carried into the ground, and is attached to a mass of buried metal. Each aërial wire will therefore form a circuit, and carry a distinct set of signals. The electric current is generated and is maintained by the use of galvanic batteries,—of which several forms are employed,—the strength of which requires to be proportionate to the distance between the extreme stations. Many varieties in the kinds of signals, and in the methods by which they are produced, have also from time to time been introduced, and the rate of transmission of messages has been greatly increased.

It is hardly possible to assign to any one person the merit of originating this very valuable invention. Like many others of like importance, it has been perfected by degrees from small beginnings, and a considerable number of scientific men and practical workers are each entitled to their due share of merit. The following brief *résumé* of the early history of the electric telegraph, abbreviated almost entirely from an interesting and valuable paper read before the Institution of Civil Engineers on March 2nd, 1852 (vol. xi. of *Proceedings*), will convey a sufficiently clear idea of the early steps by which the infant electric telegraph arrived at practical maturity.

The electric telegraph has its origin in the combination of three separate yet correlative physical forces, viz., electricity, galvanism, and magnetism. Its history is divisible into two distinct eras; the first era comprises all telegraphs in which

statical electricity (or electricity produced by friction) was the exciting agent, the second era comprehends all telegraphs in which *dynamic* electricity (or electricity produced by chemical affinity) is the acting principle. The employment of magnetism for telegraphic purposes appears to have been thought of as early as the sixteenth century. The Jesuit 'Famianus Strada,' professor of rhetoric at Rome, states in his *Prolusiones Academicæ*, published in the year 1617, that Cardinal Bembo, who died in Rome in 1547, was possessed of a plan for corresponding at long distances by magnetic electricity, *i.e.* by the '*occult sympathy*' of two needles—a notion said to be alluded to by Galileo, and also by Sir Thomas Browne. In 1774 Lesage, at Geneva, constructed an electric telegraph, composed of twenty-four wires, between two rooms. On exciting an electric machine and joining it to one of the wires, the pith ball of an electrometer belonging to it was repelled, and the motion signified a letter of the alphabet. This invention was submitted to Frederic the Great, but was never carried into execution.

In 1787, Lomond improved upon Lesage's plan and reduced his twenty-four wires to one, and various other modifications were made down to the year 1826. Amongst other inventors, about the year 1819 a Mr. Ronald, of Hammersmith, is stated to have applied electricity for the purpose of effecting telegraphic communication, and succeeded so far as to complete a current through eight miles of wire. In 1826 the first registering telegraph is said to have been constructed by Mr. H. G. Dyar, of Long Island, in America. He 'used the decomposing power of a spark, acting upon a fillet of paper moistened and stained with litmus, and moved by hand, or by clockwork. The passage of each spark from a conductor to the paper produced a discoloration, and by the different combinations of marks thus made any signal could be transmitted and registered.' This is the main principle of one of the subsequent printing telegraphs. So far, *statical* or frictional electricity had been the agent employed, but from about the year 1800, when Volta made his celebrated discovery of the pile now bearing his name, the dynamic era of telegraphy may be said to have commenced. The distinguishing characteristic of the new voltaic current was, that it flowed in a continuous stream, instead of in sudden flashes or gushes, and

the minds of inventors were directed into a new channel. In the year 1811, Sömmering—who appears to have made the first electro-dynamic telegraph—described before the Academy of Sciences at Munich his plan of a telegraph, based on employing as the means of indication the decomposition of water by a battery. He used 35 wires, which signified the 25 letters of the alphabet and the ten numerals. Soon afterwards Schweiger suggested several important improvements in Sömmering's device, and proposed a considerable diminution in the number of signals, by employing two batteries of different powers, and reduced the number of wires to two. About the same time also, Professor Coxe, of Philadelphia, devoted much time to the subject, and confidently predicted the future success of the electric telegraph.

In the year 1819 a great impetus was given to the science of electro-magnetism by Professor Oersted, who discovered that when a magnetic needle was placed above or below a wire, and a current was passed through the latter, the needle had a tendency to place itself at right angles to the current. Schweiger soon after improved on this discovery, and found that by taking a silk covered copper wire, and coiling it round several times, the deflections of a magnetic needle suspended about it became extremely sensible. Fechner conceived the idea of adapting Oersted's discovery to telegraphic purposes, but was forestalled by Ampère, who, on the 2d October 1820, read before the Academy of Sciences a description of an electric telegraph on this principle. About this period, Arago observed the magnetic properties of the electric current, and discovered the attractive power of soft iron, while Sturgeon, in 1825, constructed the electro-magnet, and noticed the increased power to be obtained from it. It is stated that Baron de Schilling of St. Petersburg, about the year 1832 or 1833, constructed an electric telegraph consisting of five magnetic needles placed in the centre of coils or multipliers, and set in motion by keys.

The main elements of the electric telegraph were thus complete, nothing was wanted but a master mind, or minds, to combine the discoveries made, and mould them into practical and workable shape. In the annals of the year 1837 four names

stand pre-eminent as claimants for the honour of inventing long-distance telegraphy, viz., Wheatstone, Alexander, Steinheil, and Morse. There appears to be no doubt of Wheatstone's priority, whose discovery was announced in the *Magazine of Useful Science* on 1st March 1837. On the 12th June of the same year, Messrs. Wheatstone and Cooke sealed their first patent 'for improvements in giving signals, and sounding alarms in distant places by means of electric currents transmitted through metallic circuits.' The five needles at first used were soon afterwards reduced to two, and numerous other patents were taken out by the same gentlemen. In July of 1837, M. Steinheil of Munich made an electric telegraph consisting of magnetic needles and coils of very fine insulated copper wire. Signals were obtained by the action of a magneto-electric machine, and he employed the earth to complete the circuit, but the apparatus was of a very complicated nature.

Professor Morse in America (one of the great names of electric telegraphy) also patented in the same year an electro-magnetic registering telegraph, employing only one wire, and consisting of an electro-magnet, the coiled wire of which forms the continuation of the line wire. The armature of this magnet was attached to the end of a small lever carrying a steel point at its opposite extremity. Under this point was a roll of paper set in motion by the aid of wheelwork. When a current was transmitted, the magnet attracted the armature, which caused the pen to press against the paper. This principle has developed into the well-known Morse registering telegraph. If the contact is rapidly made and broken by the finger-key, simple dots only are made on the paper. If the circuit is kept closed for some time, the pen or style traces a line proportionate in length to the time the circuit is closed. If no current is transmitted for some time the paper exposes a blank surface, and the combination of these dots, lines, and blank spaces, forms a symbolic alphabet.

The original system of signals employed by Messrs. Wheatstone and Cooke, consisted of a dial, on which various symbols were depicted, to which the needles—deflected by the current—were made to point. The first telegraphic line in England upon Wheatstone's plan was erected in the year 1839, between

London and Slough, on the Great Western Railway, a distance of 18 miles. In the *Journal of the Asiatic Society of Bengal*, for September 1839, is a very interesting account of Dr. O'Shaughnessy, M.D., F.R.S.—afterwards Sir William Brooke O'Shaughnessy—of a series of results obtained in April and May 1839, on a line of wires 21 miles in length constructed by him in the vicinity of Calcutta, suspended on bamboo poles. In that paper, the one-wire system, the earth circuit, the use of the induction machine, and the traversing of rivers by means of insulated wires, were prominently set forth, and accurately described, and the importance of the introduction of the electric telegraph into India was strongly urged. This appears undoubtedly to have been the first *long* line of telegraph ever constructed in any country. Interesting details relating to the construction of this line of telegraph—which presents an important if not solitary instance, of the practicability on a large scale of a great invention being first demonstrated on Indian soil—will be found in the Preface to *The Electric Telegraph in British India*, by W. B. O'Shaughnessy, M.D., F.R.S., Surgeon, Bengal Army, Chief Superintendent of Telegraphs to the Honble. East India Company, London. Printed by order of the Court of Directors, 1853, from which the following is quoted. 'In April and May 1839, the first *long* line of telegraph ever constructed in any country was erected by the writer of these pages in the vicinity of Calcutta. The line was 21 miles in length, embracing 7000 feet of river circuit. The experiments performed on this line removed all reasonable doubts regarding the practicability of working electric telegraphs through enormous distances, a question then, and for three years later, disputed by high authorities, and regarded generally with contemptuous scepticism. It is never too late to acknowledge an obligation. In the experiments then carried on I received the warm aid and support of Dr. Wallich, then Superintendent of the Botanic Gardens, Calcutta, now Vice-President of the Royal Society, London. One terminus of the line was placed in his house, and all the resources of his establishment and library were held at my disposal. He saw at a glance the marvellous future which these and simultaneous experiments in other countries foretold, and with his high name he

protected the experimentalist from much of the derision which his attempts excited in the community of Calcutta. The experiments having been completed, and the results published,[1] the line was taken down.'

It will thus be seen that India has been a pioneer in electric telegraph development. Dr. William Brooke O'Shaughnessy was afterwards intrusted with the first public lines of telegraph laid down in that country. Under his direction working lines of telegraph were rapidily established over the whole of Hindustan, the first line constructed being one 30 miles in length between Calcutta and Diamond Harbour, opened in December 1851. By the year 1858, all the seats of Government were connected by wires aggregating 3000 to 4000 miles in length, and additional telegraphic lines—at least equal in extent—were in course of construction.

By the year 1872, every important place in India was connected by telegraph, which was also in working order along the whole 5373 miles of railway then opened. Three alternative lines of cable telegraph also connected the great dependency with England. A complete system of telegraphic communication between India and Europe *viâ* Turkey, 'was planned and carried out by the late Lieut.-Colonel Patrick Stewart of the Bengal Engineers, on the failure, a few days after completion, of the original cable laid from Suez to Bombay in 1857; capital for which had been raised by a company on a twenty-five year guarantee from the Government of India. Colonel Stewart did not, however, survive to see the successful result of his labours. He died at Constantinople in January 1865, from the effects of exposure and over-exertion, a very short time before the lines were formally opened.'[2]

This Turkish line remained the principal means of telegraphic communication with India until the year 1870, when a new era dawned on the history of Eastern telegraphy. Almost simultaneously with the successful laying of the new Red Sea cable, the Indo-European Telegraph Company's line was opened to Teheran, and was carried to London by way of Tiflis, Warsaw,

[1] *Vide* No. 714-731 of the *Journal of the Asiatic Society of Bengal*, September 1839.

[2] *Moral and Material Progress Report*, 1873-74.

and Berlin. The Anglo-Persian line from Teheran to Bushire had previously been much improved, and a second wire erected. An alternative cable had also been laid from Bushire to Cape Jask, whence it was continued by land wires to Gwadur, and the Turkish Government, stimulated by the competition, took steps to improve the older service. Between the years 1862 and 1872, the Indian Government expended upwards of £1,150,000 on telegraphic communication with Europe, in addition to a sum of £18,000 annually—or half the guarantee on the original Red Sea cable. By the various routes now open, the English and Indian public enjoy the utmost facilities for the rapid transmission of intelligence from the one country to the other.

The length of inland telegraph lines opened in India under the administration of the Indian Government Telegraph Department, reached, at the end of the year 1891-92, the great total of 38,625 miles, and the capital outlay on these lines—deducting receipts on capital account—reached 521,82,804 rupees, or £5,218,380 at par of exchange. The aggregate number of telegraph offices throughout the country open for the despatch of paid telegrams at the end of the same year, was 1001 departmental and postal offices, and 2245 offices on railways and canals, or 3246 offices in all. Some of the more interesting statistics of the Indian system of electric telegraphs, during the last year for which the information is available, viz., the official year 1891-92, are as follows. The capital expenditure during the year was Rs.19,42,128, of which Rs.15,47,523 were expended on new lines. The working expenses were Rs.48,34,295, whilst the revenue derived from all sources reached a total of Rs.74,30,092, leaving a surplus of Rs.25,95,797, representing a dividend of 4·97 per cent. on the capital account. If, however, the charges for State messages, and 'news free' and other *pro forma* revenue be deducted, the net receipts by Government equalled Rs. 10,43,697, representing a net return of 2 per cent. as compared with 0·37 per cent. nine years earlier, and 2·193 per cent. in the maximum year 1889-90. The revenue receipts on account of State messages may, however, be legitimately included in estimating the return on capital outlay—including these, therefore, but deducting the 'news free,' and other *pro*

forma revenue, amounting to Rs. 49,807 only, the net receipts were equivalent to 4·85 per cent. on the capital expenditure.

During the year 1891-92, 3,808,998 messages were booked in the Telegraph Offices of the Department, to the value of Rs. 56,82,729. Of these, 3,140,690 were *private* inland or foreign messages (the number of private inland messages alone being 2,627,408). As compared with the previous year, this represents an increase of 262,380 in number, and Rs. 2,42,140 in value, equivalent to 11·09 and 9·87 per cent. respectively. During the last ten years the number of private messages has increased by about 120 per cent., and their value by nearly 100 per cent., and in the same period the number of telegraphic offices has increased 218·7 per cent. These figures show how greatly the use of the telegraph is appreciated, and how rapidly it is extending among the people of India.

At the end of the year 1891-92, the strength of the signalling establishments of the Indian Telegraph Department amounted to 2842 persons, of whom 1550 were departmental officers, 357 were British military signallers, and 935 were postal clerks. Over the enormous total of telegrams transmitted and received during the year, the number of complaints made was 1045, or 0·025 per cent. of the total number of messages. Of these about one-half, or 542, were admitted. The number of telegrams that from various causes could not be delivered amounted to 13,899, equal to 0·308 of the whole number received for transmission, the latter figures illustrating a peculiar phase of Indian civilisation.

Inland telegrams in India are classified under three main heads, viz., 'State,' 'Private,' and 'Press'; and under each of these heads the messages are sub-classified as 'Urgent,' 'Ordinary,' and 'Deferred,' subject to a decreasing scale of charge in the order named. 'Urgent' telegrams take precedence of all others; 'Ordinary' telegrams are forwarded next in order, and 'Deferred' messages are a cheap class of telegram transmitted onwards whenever the wires are clear of urgent and ordinary traffic. The year 1891-92 is the decennial year of the existing tariff with these classes: it will be interesting, therefore, to note in the case of *private* telegrams, the relative popular appreciation of the three kinds of message. During

the ten years, Urgent telegrams have increased in value by 92 per cent., Ordinary telegrams by 59·1 per cent. (sharing the fate of almost every *second* class) and deferred telegrams by 247·3 per cent. The latter cheap form of message, in fact, amply satisfies the needs of all the less important concerns in business and domestic life, and its greater relative use may be expected to steadily continue. In the 'State' and 'Press' class, the percentage of deferred telegrams during the year 1891-92 is even higher than in the case of private messages.

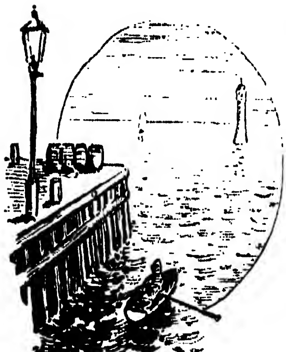
The net additions to the system maintained by the Indian Telegraph Department during the year were 1555 miles of line, 6647 miles of *wire*, and about 2 miles of cable. The total mileage of wire on the 38,625 miles of open lines was 120,159 miles (or sufficient to go more than five times round the circumference of the earth), of which 40,999 miles were in connection with the railway system, 76,819 miles belonged to imperial lines, and only 288 miles were maintained for native States; the remaining mileage being classed under private or provincial lines, or maintained in connection with canal systems.

Among the more important of the electrical improvements recently subject to careful experiment in India, are the use of 'dry' batteries to test their suitability under the varying and trying conditions of the Indian climate. The experiments with this form of battery have been attended with a promising degree of success, its chief merit being that it requires no maintenance. The application and extension of the system of duplex and quadruplex telegraphy over unusually long distances, has also made considerable progress, and the practicability of working duplex *direct* through an iron wire between Calcutta and Bombay, a distance of 1346 miles has been proved.

SEA AND HARBOUR WORKS IN INDIA

SEA AND HARBOUR WORKS

Introductory—Paucity of harbours on Indian coasts—Principal ports—Bombay —Early improvements and development—Karachi harbour—Description of port—Harbour works undertaken—Object in view—Outline of principal works—The Manora breakwater—Details of construction—The port of Karwar—Improvements effected—The open roadstead of Madras—Extract from report of a committee in 1868—Proposals for improvement of the port —Breakwater project—Enclosed harbour scheme adopted—Description and construction of the works—Main features as carried out—Disastrous effects of a cyclonic storm in 1881—Proposals for restoration of the harbour—Committee of eminent harbour engineers—The port of Calcutta—Kidderpore docks—Lighting the coasts of India—Important lighthouses—Coasts of Burma—Alguarda lighthouse—Double Island, Cocas and Khrisna shoal lighthouses—The Great Basses, and Tuticorin lighthouses—The 'Prongs' lighthouse, Bombay—Concluding remarks—Summary of aim of volume.



F all the many necessities for the carrying out of a great export and import trade in any country, secure harbours, liberally provided with suitable accessories, whether for the safety and guidance of ocean-going vessels entering or leaving them, or dry and wet docks for cleaning and repairing, or for the rapid and convenient loading and unloading of their cargoes, are as important as improved internal communications; harbours and docks being, in fact, the great transfer stations of outwards and inwards traffic from sea to land carriage, or *vice versâ*, on the road to the final destination of the merchandise. It is necessary, therefore, in this concluding section to indicate the main features of some of the chief sea and harbour works carried out on the coasts of India, although the space available will only admit a brief reference to the more important examples.

Important as harbour accommodation really is as a link in the chain of inter-communication between India and the outer world, the ports, harbours, and anchorages of the Indian coasts are singularly few in number, and have, moreover, until comparatively recent years, received a far smaller degree of attention than has been so largely devoted to the internal communications of the country. Much, however, has been done, not only in the matter of surveys, and thorough scientific investigation into the capabilities of all those places presenting the most promising features for the construction of artificial harbours,—whether as commercial ports, or as harbours of refuge, and in the gradual improvement of many of them, but also in the development on an extensive scale of the more important of these places by means of heavy and costly works. It is to these latter only—where works of especial consequence have been undertaken—that we can here refer.

Unlike most of the other great peninsulæ of the world, India, although possessing upwards of 3600 miles of coast line, is remarkably destitute of natural harbours affording accommodation and security to large ships. This disadvantage is, moreover, augmented by the circumstance that at certain seasons of the year the neighbouring seas are peculiarly liable to furious tempests and cyclones, of exceptional severity. Along the whole eastern coast of the peninsula—facing the Bay of Bengal, from the head of the bay to Cape Comorin, absolutely no really commodious natural harbour exists, although at a few places, greater or less facilities for the improvement of natural features, and the formation of artificial harbours are to be found. The Presidency city of Madras, the most important centre on this wide stretch of coast, lies on an exposed and open roadstead, and, until quite recent years, has possessed no accommodation or protection whatever for shipping.

At the head of the Bay of Bengal—in the Gangetic Delta, the port of Calcutta is situated 100 miles inland, on one of the mouths of the Ganges called the Hooghly, through which the navigation is tortuous and difficult, and affords a certain degree of accommodation for large ships. The port of Colombo, on the west coast of the island of Ceylon, has been

vastly improved of late years; Ceylon, however, being a Crown colony, is outside the limits of this volume. On the western coast of the peninsula—facing the Arabian Sea, the two principal commercial harbours are Bombay,—taking rank as the first and most important natural harbour in India—and Karachi, situated not far from the mouths of the Indus; the capabilities of which place are only of a moderate kind. On this coast also, the small natural harbour of Karwar—the port for North Canara and the cotton districts of Dharwar, affords some degree of protection, and has been artificially improved. Along the whole seaboard of India small seaports, chiefly situated in the mouths or estuaries of the principal rivers, are very numerous, and are largely used by native and English-coasting craft. Most of these have from time to time received attention in the way of dredging and deepening their available areas, or have been protected by the provision of groynes or small breakwaters. Many have been provided with wharves, quays, or landing-piers (as at Calicut)—for the convenience of the shipping, so that the aggregate amount both of work and expenditure, from local or imperial funds, on the improvement of the smaller ports along the Indian coasts, must be very considerable; a few of the smaller ports, such, for instance, as Mangalore, are said to be capable of great improvement, and in at least two cases, viz., the backwater of Cochin on the west, and the so-called 'Blackwoods' Harbour on the east coast, natural facilities appear to exist for the formation of semi-artificial harbours of some considerable importance: Cochin has, in fact, been reported of as capable of being made one of the finest close harbours in India, when it might become the outlet for the whole trade of the Southern Peninsula.

Bombay, the western sea-gate of India, and by far the best natural harbour in the country, was for a long period destitute of any suitable accommodation to enable ships to load and unload alongside quays or wharves. From about the year 1855, considerable improvements were initiated in buoying and lighting the entrance-channel. The long split of land called the 'prongs,' running out from Colaba—which for many years was a fruitful source of danger to ships, owing to the original lighthouse having been built on Colaba Island, too far

inland from the point of danger, was protected by a new lighthouse, erected at great expense $1\frac{1}{2}$ miles farther out to sea. The old Government dockyard and docks at Bombay were supplemented by a fine dry dock at Mazagon for the Peninsula and Oriental Company's steamers, on ground reclaimed from the sea on the eastern side of Bombay Island. This dock was constructed 382 feet long inside gates, $53\frac{1}{2}$ feet wide at bottom, 79 feet wide at top, and $26\frac{1}{2}$ feet deep, but approachable only by large vessels at spring-tides. The increasing need of wet-dock accommodation at Bombay gradually led to the construction of extensive works of this character, on the site known as the Elphinstone Estate, which was reclaimed from the sea by the Elphinstone Land and Dock Company, and dock construction at this port has greatly extended, so as in great measure to keep pace with the growing necessities of the sea-borne trade.

The harbour of Karachi, situated near the mouths of the Indus, and slightly nearer in a direct line to the entrance of the Red Sea at Aden, than is Bombay, is the port of Scinde, and—through the Indus river and valley railway—of the whole Punjab. It thus occupies a very important position, and has now for some time enjoyed a large and growing prosperity. The harbour, which in point of accommodation can never seriously rival Bombay, is essentially a backwater, having an area at high tides of 15 to 18 square miles; but a very considerable portion of this is only very lightly covered by the tidal flow. The range of the tide is rather over 7 feet at main springs, and sometimes 10 or 12 feet at extraordinary springs. The western half of the harbour is formed by a long narrow strip of sand, ending in a rocky promontary at Manora Point, and the eastern side is formed by the low sandy island of Keamari. The main entrance for ships is between the western side of Keamari and Manora Point. Across this entrance a sand-bar had formed nearly 3000 feet in width, with a depth over it at low water spring-tides of $1\frac{1}{2}$ to 2 fathoms only; the bar having been formed by the action of the south-west monsoon current driving forward the loose sand lying immediately off the extremity of Manora Head. It was to remove this bar, and preserve a permanent and deep-entrance channel that the works carried out at Karachi were mainly undertaken.

The chief objects in view were, to increase the volume of water passing through the entrance at each tide; to give the current a proper direction, and to shut out as much as possible the heavy south-west seas from the mouth of the harbour. A secondary entrance was originally situated between the mainland and Keamari Island, called the Chinna Creek, and the first object was gained by blocking up this entrance, so as to force all the water through the main entry—and by opening a passage through a long mole or dyke which had been previously constructed by Sir Charles Napier, from Karachi town to Keamari Island, but without any opening. The second object was secured by running out a long groyne from Keamari Island to seaward, so as to direct the whole force of the tide on the bar; and the third, and the principal operation, was the construction of a breakwater extending to seaward from Manora Point, to break the force of the heavy seas. These works were aided by continuous dredging on the bar to assist the tidal scour, and the removal by blasting of a rocky obstruction at 'deep-water point,' on the west or Manora side of the harbour.

The blocking of the Chinna Creek, or eastern inlet entrance—including the construction of an iron screw-pile bridge 1200 feet long, over the opening made in the Napier mole, together with the principal subsidiary operations in the deep-water channel, cost altogether nearly £130,000. A new jetty near the town-end of the harbour, where goods could be landed and shipped by the smaller craft, cost £43,000; and the Keamari groyne, which was commenced in November 1861, and completed in 1865, cost over £48,000. The closing of the Chinna Creek, 980 feet across, was completed in the year 1873.

The construction of the valuable Manora Point Breakwater was commenced in 1869, and it was completed in the year 1873, at a cost, including plant and establishment, of rather under £100,000. This breakwater is of especial interest, both on account of the novel features of its design, and as being the first that was constructed in deep water with a view to break the force of the heavy seas raised by the south-west monsoon on the west coast of India. It runs in a SSE. direction from the southern extremity of Manora Point, for a distance of

1503 feet beyond low-water mark, terminating in a depth of 5 fathoms, or 30 feet at low water. For the first 500 feet of its length the water at low tide is 2 to $2\frac{3}{8}$ fathoms only, and the irregular sea-bottom consists of conglomerate rocks, wholly or partially imbedded in sand: the bottom along the remaining outer portion consists of sand resting on a bed of clay. The base of the breakwater is formed of a heavy bank of rubble stone thrown to the sea-bottom from boats; and the top surface of this bank was levelled off by divers at a height of 15 feet below low water in the deeper, and 10 feet in the shallower portion towards the shore end. Upon this rubble bank, made with ample width, and side slopes of 1 to 1, was raised a solid superstructure, consisting of a vertical double wall built up of huge concrete blocks, each 12 feet long, 8 feet high, and $4\frac{1}{2}$ feet thick, weighing 27 tons. These blocks, which were placed on edge, with a backward rake or inclination towards the shore of 3 inches to the foot—to prevent movement during the progress of the work—form a wall 24 feet high and 24 feet wide. The cross section of this wall presents six blocks, two, without bonding, forming the width, and three the height.

The manufacture of the large concrete blocks was carried on on shore by the aid of concrete mixing machinery: they were made in moulds of the requisite dimensions, and contain one-eleventh in bulk of Portland cement, mixed with conglomerate and sand. After being allowed a suitable interval to dry and harden, they were—by means of a special machine—lifted on to trucks, and run out to the breakwater, where they were deposited in place by the aid of a powerful 'Titan' or travelling crane, with projecting arm of special construction; the lifting and lowering tackle being worked by a powerful steam-engine.

The Manora breakwater was virtually completed in 1873, at the very moderate cost, exclusive of establishment, of £69,489. The total cost of the Karachi Harbour improvement works, up to the year 1873-74, was about £450,000; their united effect has been entirely satisfactory. A new direct entrance channel, preserving a depth of 20 feet at low water, was formed, and the harbour was rendered accessible to vessels of the largest size, whilst at the same time the

capacity of the anchorage was considerably increased. The breakwater, which has sustained no serious injury from the violence of the sea to which it is exposed, permits the use of the port at all seasons, and allows the regular arrival and departure of the mail-steamers. At Keamari—no longer an island—a landing-pier, and extensive wharfage, has been constructed, to which the railway has now for many years been extended, and the possession of an excellent, though moderate-sized harbour, out of the track of cyclones, and situated 500 miles from the nearest good harbours on either side of it, ensures to Karachi a continuous growth of trade, and commercial as well as military and naval importance.

The port of Karwar, on the west coast, about 50 miles south of Goa, consists of a bay or cove, partially protected from the south-west monsoon. In the year 1858, an English harbour engineer of eminence was deputed to report on its capabilities as a harbour of refuge. He reported that the bay was in great measure protected from the most violent south-west winds, but was exposed to the west and north-west, and recommended the construction of breakwaters, aggregating a mile and a half in length, by means of which a perfectly quiet harbour, of upwards of 4 square miles in area, would be formed, with a depth varying from 14 to 32 feet at low water. In 1860 it was determined to effect some improvements in this natural harbour, in order to render it available as a port for the shipment of cotton from Dharwar. A road was constructed to connect it with that district:—Along the east side of the bay a wharf-wall of masonry, 845 feet long, was built, and a landing-place was formed by excavating the hill-sides, which here descend nearly to the water's edge. It was at first intended to construct a screw-pile pier 200 feet long, with a T head of 90 feet, and the necessary materials for this pier were obtained from England in 1864, but, owing to unexpected difficulties met with in securing the piles in the treacherous soil, the pier materials were utilised in the construction of a landing-stage, about 100 feet square, commanding 7½ feet at low water, and extending 45 feet beyond the wharves. A lighthouse was also built on the Oyster rock, westward of the port, the light of which is 205 feet above the level of the sea. The harbour improvement

works at Karwar were estimated to cost £115,000, including a wharf road and iron bridge costing £65,000.

The condition of the Madras open roadstead, as a port of call for vessels, was thus referred to by the members of a committee appointed by Government in the year 1868 to report on the best method of improving the facilities for the sea-borne trade at that place. They say:—'The port of Madras at the present time, so far as the facilities for trade are concerned, differs very little from what it was nearly 250 years ago, when, as a small fishing village, it first attracted attention. It remains an open roadstead, destitute of any natural shelter, and still unprovided with any artificial substitute; and its surf still offers an insurmountable difficulty to the passage of boats of every kind, except the primitive Masulah boats. But though manned by thirteen trained men, a Masulah boat carries only $1\frac{1}{2}$ tons as an ordinary load in the finest weather, and often less than half a ton in heavy weather. The very skill of the boatmen is one of the difficulties of the port, for their numbers being limited, they are able to set regulations at defiance, and to charge pretty much what they like—twice, four, and six times the legal hire being a common rate, and ten times by no means uncommon; well knowing that the course which would elsewhere be followed of importing additional men from other localities would be inoperative at Madras, for in consequence of caste prejudices, and the disinclination of natives to adopt customs, or to follow trades which have not been followed by their fathers before them, the ordinary laws of political economy cannot be applied in their integrity in this country, and it does not follow that because there is a greater demand than supply of Masulah boatmen, and a very handsome profit to be reaped by those who might qualify for the occupation, that outsiders will qualify for it, and come forward to break the monopoly. The great objections then to the port of Madras are—First, That it is an open roadstead, destitute of shelter, which renders it necessary on the approach of a gale for ships to put to sea for safety; or if out of trim and ballast, and unable to put to sea, to incur the imminent risk of dragging their anchors, or of parting from them and going ashore complete wrecks. Secondly, That owing to the com-

munication between the shipping and the shore being for the most part by Masulah boats, only carrying 1½ tons at a time, the delay in loading and unloading is so great as to deter many ships, to which a preference would be given, from coming to the port at all. Thirdly, That the actual cost of landing and shipping cargo, even at legal rates, is needlessly great, while the much higher rates which the mercantile community pay on demand, rather than incur the inconvenience and odium of prosecuting the boatmen, enhances the cost so much as to become a formidable addition to the charges of a port otherwise regarded as a cheap one. Fourthly, That, notwithstanding the skill of the boatmen, the damage to goods from spray, and from shipping seas in crossing the surf, is a very serious consideration.'

Some time before the date of this report, a screw-pile pier, projecting some 300 or 400 yards from the shore, had been constructed with a view to lessen the evils above depicted. The committee recommended the construction of a breakwater 2000 yards long, lying parallel with the shore, and distant about 1200 yards from it, in 7 or 8 fathoms of water, the cost of which they considered might reach about 1⅓ million sterling. They were of opinion that a closed harbour would be preferable to a breakwater, but the majority of the members believed that the danger of shoaling from the advance of sand—the long shore movement of which would be arrested by the projecting piers of a closed harbour—would be an insuperable objection.

From this time numerous proposals were made and lengthily discussed, until, in the year 1872, a project for the construction of a closed harbour was submitted by an experienced English harbour engineer, whose services in the following year were secured for a period of twelve months, in order that he might fully investigate the subject. The scheme proposed was, the construction of two piers to be run out for 1200 yards at right angles to the foreshore, and placed about 500 yards north and south of the existing screw-pile pier. These side piers to be connected at the ends by a cross-pier or breakwater, running parallel with the shore, with an opening, 150 yards wide in the centre, as an entrance into the closed harbour which would

thus be formed. It was proposed that the piers should be constructed generally after the pattern of the Manora breakwater at Karachi, viz., a rubble-stone bank or mound, brought up from the sea-bottom to a depth of 22 feet below low water, on which would be built a vertical wall 24 feet thick, of large concrete blocks—each weighing 27 tons—capable of resisting the force of the waves. The cost of this close harbour was estimated at £565,000, and the enclosed area available for ships would be a rectangle about 1000 yards long by 830 yards wide, or 170 acres, with a depth at low water of from 3 to 7 fathoms, with a further space of about a quarter of that area, with a depth of less than 3 fathoms for boats, lighters, and native craft. The question of the probable advance of the foreshore was discussed, and it was considered that the accumulation of sand would at first be heavy, but that when once the piers were extended into the deep water the further advance would be so slow as practically to remove to a very distant date any danger of the harbour shoaling up.

This scheme was generally approved by the Government of India in 1874, after much discussion of its details, and much opposition by the advocates of the breakwater alternative, but on various counts the Government raised the estimated cost from £565,000 to £776,000. In the following year the sanction of the Secretary of State to the construction of the proposed harbour was communicated, with the following liberal remarks on the estimates of probable expenditure :—'The contingencies upon which the cost of constructing and repairing a harbour depends are so uncertain that it would be hazardous to express a confident opinion in respect to these conflicting estimates. But the question is too large to be dealt with only on financial grounds. Many human lives are sacrificed in the tempests which annually ravage the Coromandel coast, and it is possible that a large proportion of these might be saved if vessels which are now surprised in the roadstead could seek the shelter of a harbour. The material interests of a vast population that inhabits the Presidency of Madras are not less deeply affected by the unsheltered condition of the port. It can hardly be doubted that if a safe and regular access to the sea could be secured to them, their industry and trade would be greatly

stimulated. The public utility of a harbour can seldom be measured by the actual return in the shape of dues which it can be made to pay, and in the Presidency of Madras, where the destitution of shelter upon the seaboard is so remarkable, such a principle of valuation would be specially misleading.'

The work of construction on the North Pier was put in hand in December of the year 1876, the South Pier not being commenced until about a year later. In carrying these piers through the shoal water, much trouble and delay was occasioned in consequence of the rapid accumulation and advance of sand, but, as had been confidently anticipated, as soon as the 4-fathom line was reached, all difficulty on this head ceased, and the work was carried on without further interruption. The general features of the work as carried out were as follows: —The rubble stone base was made 78 feet wide at the top, with side slopes of 1 to 1; its height varied with the depth of water, being about 25 feet at the deepest part, where the top of the mound was 22 feet below the water. The rubble was deposited *in situ* from steam-hopper barges, and its surface was levelled by divers to receive the concrete blocks. The foundation blocks were 14 feet long, 6 feet wide, and 4½ feet thick; those forming the remainder of the wall being 12 feet by 8 feet by 4½ feet, weighing 27 tons each; upwards of 13,643 blocks were used; they were laid, with a backward rake of 3 inches to the foot, by the aid of powerful 'Titan' cranes with overhanging arms. The walls were constructed without bond, the width of 24 feet being made up of two parallel walls of blocks resting on, and in side contact with each other, each block having a tenon on its upper surface, and a corresponding mortice on its lower surface to prevent slipping. The greatest depth of water in which the piers were founded was 8 fathoms, or 48 feet. Towards the ends, forming the central entrance into the harbour, the pier-heads were widened out to about double width. The total length of the piers (those to the north and south being of nearly equal length) was 7856 feet.

With the exception of a small re-entering curve, which it was proposed to add at the pier-heads, the works were practically completed towards the end of the year 1881, when, on the 12th November of that year, a severe cyclonic storm occurred,

raising exceptionally heavy rollers and ground swell, although unaccompanied by any very violent wind. The result of this storm was to wreck nearly the whole of the outer, or breakwater face of the harbour, from the elbows, or turns of the pier-walls, where the injury was greatest, to the entrance on either side; the side piers, from the shore to the elbows, being but little affected. In the case of this storm, the action of the sea was sufficiently severe to undermine foundations at a depth of 22 feet under low water, an action far in excess of that hitherto held possible by harbour engineers in England, where a depth of 15 feet below low water was considered as safe against all possibility of disturbance by the worst waves.

This regrettable incident caused a suspension of operations for some time, and gave rise to a long discussion as to the most secure methods of restoring the harbour. The recommendations of a committee, composed of eminent harbour engineers, which was appointed in England in the year 1883, advising a certain remodelling of the works, estimated to cost £430,000, were eventually in the main adopted, after very considerable opposition had been offered by the local, nautical, and other authorities in Madras, who advocated the closing of the outer or easterly entrance to the harbour, and the construction of a new and wider entrance in the north-east angle. This proposal, after a long discussion, was, however, overruled, and the restoration of the harbour on the main lines recommended by the English committee was ordered. The final estimate for the restoration works reached a sum of £459,000, so that, with the original outlay up to the time of the storm, the estimated completed cost of the Madras harbour ranged not far short of a million and a quarter sterling.

There is little of general interest that need be here referred to in connection with the port of Calcutta. That portion of the Hooghly tidal channel abreast of the city, chiefly occupied by the shipping frequenting the port, is from 4 to 5 miles long, and averages about 300 yards in breadth. A considerable extension of wharves and jetties along this water frontage has from time to time been carried out by the port authorities, and the provision of wet dock accommodation, somewhere at or near Calcutta, is a question which in one form or another

has been under discussion for the best part of half a century. Much difference of opinion has existed as to the most suitable position for the construction of commercial docks (or even whether such docks were necessary at all), and numerous proposals have been put forward. Diamond harbour—situated about 50 miles lower down the river, or 31 miles by land from Calcutta—has been particularly favoured. Proposals for the construction of docks at this place were made so far back as the year 1839, and were again urged in 1847, when, chiefly on the opposition of Lord Dalhousie, the project was shelved. A special committee, appointed to consider the question of dock accommodation at Calcutta in the year 1883, was also favourable to the revival of this scheme, but an important and influential minority, composed of all the mercantile members, agreed in rejecting it. Another committee, subsequently appointed to pursue the investigation, came to a unanimous conclusion against Diamond harbour, and was in favour of the construction of docks at Kidderpore, on a site situated on the Calcutta side of the river, about $3\frac{1}{2}$ miles from the city. The estimated cost of these docks, including subsidiary works and interest, was 265 lakhs of rupees, or £2,650,000; the area of dock accommodation proposed being nearly 111 acres, consisting of a tidal basin of $9\frac{2}{3}$ acres, and two docks of $36\frac{1}{3}$ and $64\frac{3}{4}$ acres respectively. The approval of the Home Government in the year 1884 was, however, on general prudential grounds, limited to the tidal basin, and the smaller of the two docks only, and to the expenditure of a sum not exceeding 200 lakhs, or £2,000,000 sterling.

Considerable difficulty was experienced by the Port Commissioners in raising the necessary funds, and much discussion and differences of opinion as to the kind and degree of financial assistance to be rendered by the Government occurred. It was clear that the latter, as the owners and guarantors of so large a mileage of railways converging on Calcutta, were intimately concerned in the forwarding of all port arrangements promising facilities to trade, but from various causes it was not until the year 1886 that a final agreement between the Government and the Port Commissioners was arrived at, that the money required for the prosecution of the Kidderpore Docks should

be raised in India by Government loan, and lent as required to the local authority; the interest charged being the actual rate of borrowing—plus 1 per cent. for a sinking fund, to be invested at the end of four years after the completion of the docks. The work was accordingly undertaken, but whether, under the conditions of the port, the number of ships using the new Kidderpore Docks is likely to be such as to render them a financial success, it is as yet probably too early to determine.

Although the lighting of the coasts of India is by no means perfect, a great deal has from time to time been done, especially on the Burma seaboard, so that there are now probably upwards of seventy lighthouses or lightships stretched along the great extent of coast from the Manora light at Karachi to the Malay peninsula. Some of the more important of these lighthouses occur on the coast of Burma, such as that erected on the Alguarda reef, a short distance off the mouth of the river Negrais. This graceful tower is 120 feet high, showing a light 143½ feet above high-water spring tides, and has a base diameter of 42½ feet. It was completed in the year 1865, at a cost of about £100,000. The Double Island Lighthouse, situated near the mouth of the Bassein river, 56 feet in height, with a light 134 feet above high water, costing about £6000. The Cocas Island Lighthouse, 72½ feet high, with light 195 feet above sea level, built on Table Island north of the Cocas, off the coast of Burma. This lighthouse is an iron-plated tower, and cost nearly £12,000. The Khrisna Shoal Lighthouse, in the Gulf of Martaban, is erected on iron screw-piles, screwed to a depth of 24 feet into the sea-bed in 3 fathoms of water at low tide, where it is exposed to the heavy seas raised by the south-west monsoon. The tower is 84 feet in height, and it cost upwards of £16,000. The Great Basses Lighthouse, off the coast of Ceylon, is a granite tower, containing 37,365 cubic feet of that stone. It is 97½ feet high, and cost £64,000.

The 'Prongs' Lighthouse at Bombay, about 1½ miles to seaward of the old lighthouse on Colaba Island, has already been referred to. This tower, owing to the nature of the bottom, was founded on a great thickness of concrete, enclosed

in a massive dam faced with concrete blocks of large size. It is built of hard grey trap, and is 42 feet in diameter at the base, and 16 feet at the top; the total height being 127½ feet. The central core of the shaft is 12 feet in diameter, divided into eight stories, each 12 feet high. The lighthouse at Karwar, also already mentioned, is built on the Oyster rock, about 3 miles westwards of the port, a rock which rises 160 feet above the sea. The lighthouse was finished in 1864; it consists of a circular tower 45 feet high, with the light 205 feet above sea-level. These various lighthouses are all provided with dioptric lights of the first order. Along the coast of the Madras Presidency there are numerous lights of all classes, including a fine tower 90 feet high, with a dioptric light of the second order at Alepy, and one 82 feet high, with a fixed white light at Tuticorin, first lighted in 1874. These are a few examples of prominent lighthouses erected on the Indian coasts.

Concluding Remarks.

In the foregoing pages, all the principal fields of operation in connection with public works in India have been separately brought before the reader, and, although the large compass of the entire subject has compelled a very condensed treatment of individual departments, and especially of individual works, it is hoped that the main object of conveying to the mind of the reader a more comprehensive idea than he may have previously entertained of the immense extent and variety of Indian public works, and of their great importance and value to the country and to the Government, may at least have been partially attained. Statements exhibiting mere money expenditures on works of public usefulness, are necessarily a very imperfect expression of their real value, it has, therefore, been sought not only to interest the reader in the constructive details of Indian public works themselves, and to convey some idea of the dimensions and comparative magnitudes of the foremost examples; but it has been endeavoured at the same time to depict the astonishing manner in which as a whole, they have affected the general welfare; whether in ameli-

orating the material conditions of life by advancing the average wealth and wellbeing of the people, or by increasing industrial activity and improving the public revenues.

The enormous increase given to the productive capacity of the country by the labours of the engineer in India, is in truth incalculable, and the improvement, there as elsewhere, is plainly written on the face of the land, and in the wonderfully increased resources of the Government on every side. Scientific and practical engineers as a body, are commonly far too absorbed in the details of their multiform occupations, and too careless of the unconscious injustice and ingratitude with which their arduous and exceptionally responsible labours are so often requited by an unreflecting public, to go out of their way to assert the true greatness and importance of their profession in relation to the world's advancement. It is in backward and undeveloped countries that its true value is the most clearly exemplified, because it is in these, that the immediate springs and sources of progress are the most clearly visible to the public eye.

Mr. Alfred Milner, in his recent work on Egypt, relates that when a native statesman, and one of those most intensely opposed to British interference in the country, was asked by him how he imagined the country would get on without the English irrigation engineers, replied, 'You do not suppose that if Great Britain were to retire from Egypt we should let the engineers go?—I myself should be the first to do everything I could to retain them.' The true secret of the successful financial administration of Egypt under British guidance was here too patent to be overlooked or obscured, and found natural expression in the above remark. The same author—his own sympathies and interest lying naturally in the direction of finance—admits that the efforts of the British financial advisers in Egypt would have been thrown away but for the work of the irrigation engineers, he says, 'We at the finance office have, so to speak, registered that improvement in our easier budgets and growing surplus, but it is the engineers who have created it.' Among the numerous bodies of engineer officers of all classes who, under the wise initiation or direction of the Government, have for so many years been engaged with

untiring industry in laying the foundations and steadily building up the material prosperity of India, many individuals of widely varying degrees of professional aptitude and capacity may no doubt be found, and there, as in every other part of the world, various degrees of success and failure will be found to have attended individual efforts; but the prodigious transformation effected in the country, and the success and economy with which, as a whole, the great railway and irrigation works of India have been created and administered, is the test to which the body of Indian engineers—whether working directly in the service of the Government, or under the supervising control of the Government officers—may confidently appeal.

To recapitulate: It has been the chief aim of this volume, however imperfectly attained, to exhibit on a single canvas an outline picture of the more important works of public utility which have been carried out in India by British or native engineers, and to emphasise their special value, meaning, and importance. The enormous aggregate of Indian public works may be regarded as the fundamental basis of that notable advance in the material prosperity, wealth, and culture of the peoples of India which has taken place mainly within the last thirty or forty years—which, alone has rendered this advance possible, and without the existence of which the best efforts of British civil administration, British finance, education, and British laws, would assuredly have been as a few grains of wheat cast into a wilderness. The judicious extension throughout India of great public works of all kinds, under the Government of Great Britain, is the true cause of the existing remarkable development of the average standard of individual wealth and comfort among all classes of the Indian people: of the great increase in population, the steady improvement in the Government revenue, and the generally improved financial condition of the country compared with what these severally were within comparatively recent memory.

The rapid internal development of the resources of India by means of public works, irrigation canals, telegraphs, and, above all, by railways, has, moreover, not only assured material prosperity, but has also rendered possible that simultaneous and marvellous moral, and intellectual progress, and that steady

overturning of pernicious superstitions and caste trammels, which to-day is so profoundly affecting the whole social life of the heretofore stagnant races of the continent. To be assured that this is so, it is only necessary to try and picture in imagination what would have been the present comparative condition of a poorly irrigated, roadless, and rail-less India.

The mean level of human progress and of human wellbeing bears a direct proportion to the greater or less application of the practical sciences to the purpose of relieving the necessities and satisfying the wants and aspirations of man, and enlarging the sphere of his possible activity: to the power he possesses of favourably moulding his environment by bending the great sources of power in nature to his service and convenience. To realise this truth it is sufficient to contrast the rate of advancement of the civilised nations of the world during the present century with that of the whole antecedent historical period: to compare the India of the present day with the India of forty years ago. It is on the firm foundation of a steadily augmenting material prosperity created by the great public works of the country, that the beneficent English administration of India has its support, and it is on this foundation that it has alone been possible to erect that magnificent superstructure of moral government, which is at once its justification and the admiration of the civilised world.

APPENDICES

Appendix A.—Punjab Canals. 1890-91

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated 1890-91.	Value of Irrigated Crops 1890-91.	Capital Outlay up to end of 1890-91.	For Year 1890-91. Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	Results, including Interest, from commencement.
		Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	£
Major Works. Canals in operation only.	Swat River Canal,	22	...	140	88,875	247,518	360,349	14,139	3·92	+297	-88,907
	Western Jumna,	280	243	911	388,505	2,111,943	1,119,283	103,366	9·23	+60,984	+2,995,919
	Bari Doab, .	362	...	1048	535,045	1,624,008	1,643,356	132,777	8·07	+69,618	+128,668
	Sirhind, British,	319	143	2445	600,162	1,712,936	2,328,739	106,351	4·05	+17,285	-854,540
	Sirhind, Native,	223	46	1940							
	Chenab, . . .	91	...	283	52,390	182,007	570,315	482	0·08	-17,934	-77,127
	Lower Sohag and Para, .	95	...	41	38,604	107,164	69,156	-1,621	*	-4,245	-13,442
	Sidhnai, . .	58	...	146	122,525	252,949	93,575	10,181	10·88	+6,742	+25,496
Total Major Works, . .		1450	432	6954	1,826,106	6,238,525	6,184,773	365,675	5·91	+132,747	+2,116,067
Minor Works and Navigation.	Five Works and Madhopur Workshops, .	2608	...	591	1,016,552	2,577,252	187,669	35,638	19·0	+35,638	+812,657
Grand Total for Province, .		4058	432	7545	2,842,658	8,815,777	6,372,442	401,313	6·33	+168,385	+2,928,724

Appendix B.—North-west Provinces Canals. 1889-90.

Head of Account.	Names of Canals, etc.	Main Canal and Branches	Of which are Navigable.	Distributing Channels.	Area Irrigated, 1889-90.	Value of Irrigated Crops, 1889-90.	Capital Outlay up to end of 1889-90.	For Year 1889-90. Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	Results, including Interest, from commencement.
		Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	£
Major Works.	Betwa Canal, .	168	*	321	24,282	72,138	416,417	-41,711	-1	-19,927	-123,556
	Upper Ganges, .	456	213	2523	807,574	2,999,200	2,839,360	191,012	6·73	+84,380	-260,670
Canals in operation only.	Lower Ganges, .	557	199	2078	499,894	1,548,747	3,309,602	58,411	1·76	-63,620	-184,877
	Agra Canal, .	134	123	565	178,254	499,133	912,710	43,633	4·78	+9,873	-236,295
	Eastern Jumna, .	130	*	640	243,817	932,421	333,705	72,657	21·77	+60,313	+1,357,699
Total Major Works, . .		1445	535	6127	1,753,821	6,051,639	7,811,794	361,543	4·63	+71,021	+552,301
Minor Works and Navigation.	Three Systems and Jhansi and Hamirpur Lakes	20	*	519	125,582	475,595	247,506	9020	3·27	9,020	+137,316
Grand Total for Province, .		1465	535	6646	1,879,403	6,527,234	8,059,300	370,563	4·60	80,041	+689,617

Appendix C.—Bengal Canals. 1890-91.

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated 1890-91.	Value of Irrigated Crops 1890-91.	Capital Outlay up to end of 1890-91.	For Year 1890-91. Net Revenue earned.	For Year 1890-91. Per ct. on Cap.	For Year 1890-91. Results, including Interest.	Results, including Interest, from commencement.
		Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	£
Major Works. Canals in operation only.	Orissa Canals, .	252	177	765	180,299	391,059	2,476,411	-6,316	-0·25	-108,475	
	Midnapore Canal,	72	72	339	82,002	188,605	842,837	+3,576	·0·42	-30,236	
	Hidgellee Tidal Canal, . .	29	29	...	...	...	204,739	-2,553	-0·21	-10,238	-4,029,596
	Sone Canals, .	367¾	218½	1211	281,014	1,080,820	2,643,336	-2,480	-0·09	-99,062	
Total Major Works, . .		720¼	496½	2315	543,315	1,660,484	6,167,323	-7,774	-0·12	-248,011	-4,029,596
Minor Works and Navigation.	Six Systems, Two being Navigation Canals only, . .	163¾	144½	...	2,226	4,997	1,032,873	+26,363	2·55	+23,562	+1,275,343
Grand Total for Province, .		884	641	2315	545,541	1,665,481	7,200,196	+18,589	0·025	-224,449	-2,754,253

Appendix D.—Madras Canals. 1890-91.

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	of which are Navigable.	Distributing Channels.	Area Irrigated 1890-91.	Value of Irrigated crops 1890-91.	Capital Outlay up to end of 1890-91.	For year 1890-91. Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	Results, including interest, from commencement.
		Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	£
Major Works.	Godavery Delta,	506	496	1732	680,495	1,574,679	1,273,203	157,419	12·36	+ 114,067	Not Given.
	Kistna Delta, .	325	284	1614	463,071	1,123,705	1,001,052	131,663	13·15	+ 95,370	
	Pennair Anicut,	22	...	120	65,080	130,679	187,540	10,641	5·67	+ 4,129	
	Sangam Do. .	9	...	250	68,224	165,996	364,001	7620	2·09	− 4,262	
Canals in operation only.	Kurnool Cuddapah Canal, .	190	190	313	24,848	70,050	2,164,131	− 3768	− 0·17	− 90,334	
	Barur Tank, .	7	...	22	2,774	8,002	41,133	59	0·14	− 1,479	
	Kaveri Delta, .	844	...	1250	1,013,344	2,530,345	177,945	66,154	37·18	+ 59,530	
	Srivaikantham Anicut, . .	28	...	62	28,896	33,929	145,154	2652	1·83	− 2,752	
Total Major Works, . . .		1931	970	5363	2,346,732	5,637,385	5,354,159	372,440	6·95	+ 174,269	
Minor Works for which Capital and Revenue Accounts are kept—22 Works, . .		1158	304½	1264	421,043	833,961	1,405,532	28,902	2·05	+ 28,902	
Minor Works for which no Capital or Revenue Accounts are kept, ...		not given	...	not given	2,746,409	not given	not given	406,485	...	+ 406,485	
Agricultural Works, . . .		...	...	...	...	...	...	− 56,949	...	− 56,949	
Grand Total for Presidency, .		3089	1274½	6627	5,514,184	6,471,346	6,759,691	750,878	...	+ 552,707	

Appendix E.—Scinde Canals. 1889-90.

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated 1889-90.	Value of Irrigated Crops 1889-90.	Capital Outlay up to end of 1889-90.	For Year 1889-90.			Results, including Interest, from commencement.
								Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	
		Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	£
All Works by Districts.	Bigari Canals,	443	...	...	350,261	...	...	...	...	...	...
	Shikapur Canals,	338	...	...	135,574	...	...	...	...	...	...
	Ghar Canals,	784	...	...	404,828	...	...	...	...	...	...
	Eastern Nara,	293	...	...	174,936	...	...	...	...	...	...
	Hyderabad Canals,	1670	...	...	364,297	...	...	...	...	...	...
	Fuleli Canals,	1141	...	...	290,657	...	...	...	...	...	...
	Karachi Canals,	1265	...	...	256,710	...	...	...	...	...	...
Major Works,		...	...	...	...	...	850,730	72,701	8·54	+39,951	+153,238
Minor Works,		...	...	...	...	...	332,907	73,047	22·0	+60,409	+1,127,675
Minor Works for which only Revenue accounts are kept,		...	...	...	...	...	...	104,711	...	+104,711	not given.
Agricultural Works,		...	...	...	...	...	...	-18,094	...	-18,094	...
Grand Total for Province,		5924	...	...	2,349,819	not given.	1,183,637	232,365	...	+186,977	+1,280,913

Appendix F.—Bombay Canals. 1890-91.

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated, 1890-91.	Value of Irrigated Crops, 1890-91.	Capital outlay up to end of 1890-91.	For Year 1890-91. Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	Results, including Interest, from commencement.
		Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	
Major Works. Canals in operation only.	Nira Canal, . .	95½	...	109	16,913	34,731	500,244	560	...	- 18,396	Not given.
	Mhasvud Tank,	27	...	66½	7,106	18,815	203,477	670	...	- 7,214	
	Hathmati Canal,	21	...	30	3,766	11,166	51,829	71	...	- 1,893	
	Lower Panghra,	...	...	45	2,390	3781	45,607	626	...	- 1,107	
	Kadva River Works	21¼	...	15	2,227	6,553	71,895	310	...	- 2,443	
	Pravara (Lakh Canal),	23	...	11	433	2,621	37,196	-235	...	- 1,640	
	Mutha Canal and Reservoir,	88	...	67	11,201	158,646	630,713	13,776	...	- 10,449	
	Ekruk Tank, .	48	...	...	2,598	15,131	133,341	1,099	...	- 3,813	
	Krishna Canal, .	61½	...	...	3,950	45,750	84,031	1,749	...	- 1,431	
Total Major Works, . .		385¼	...	343½	50,584	297,194	1,758,333	18,626	1·06	- 48,386	
Minor Works and Navigation	Sundry—27 Works.	220¾	...	220¼	25,317	102,575	704,132	3,494	0·5	- 22,357	
Minor Works. Only Revenue Accounts kept.	1270 Separate Works.	not given	...	not given	145,563	not given	...	33,111	...	+ 33,111	
Agricultural Works.	Drainage and Protective Works.	...	...	...	...	...	2,559	802	...	+ 802	
Grand Total for Presidency, without Scinde.		606	...	563¾	221,464	399,769	2,465,024	56,033	2·2	- 36,830	

Appendix G.—General Abstract for all India, 1890-91,

*Except Scinde, and North-west Provinces, which are for 1889-90.**

Head of Account.	Names of Provinces.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated 1890-91.*	Value of Irrigated Crops 1890-91.*	Capital Outlay up to end of 1890-91.*	For Year 1890-91*. Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	Results, including Interest, from commencement.
		Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	£
Major Works. Canals in operation only.	Punjab, . .	1,450	432	6,954	1,826,106	6,238,525	6,184,773	365,675	5·91	+132,747	+2,116,067
	N.-W. Provinces,	1,445	535	6,127	1,753,821	6,051,639	7,811,794	361,543	4·63	+ 71,021	+ 552,301
	Bengal, . .	720¼	496½	2,315	543,315	1,660,484	6,167,323	-7,774	-·12	-248,011	-4,029,596
	Madras, . .	1,931	970	5,363	2,346,732	5,637,385	5,354,159	372,440	6·95	+174,269	Not given.
	Scinde, . .	5,924	...	...	2,349,819	Not given	850,730	72,701	8·54	+ 39,951	+ 153,238
	Bombay, . .	385¼	...	343½	50,584	297,194	1,758,333	18,626	1·06	- 48,386	Not given.
Total Major Works, . .		11,855½	2433½	21,102½	8,870,377	19,885,227	28,127,112	1,183,211	4·26	+121,591	No total available.
Minor Works and Navigation. Do. with lesser works and Agricultural.	Punjab, . .	2,608	...	591	1,016,552	2,577,252	187,669	35,638	19·0	+ 35,638	+ 812,657
	N.-W. Provinces,	20	...	519	125,582	475,595	247,506	9,020	3·27	+ 9,020	+ 137,316
	Bengal, . .	163¾	144½	...	2,226	4,997	1,032,873	26,363	2·55	+ 23,562	+1,275,343
	Madras, . .	1,158	304½	1,264	3,167,452	833,961†	1,405,532	28,902	2·05	+ 28,902	Not given.
							...	349,536	...	+349,536	
	Scinde, . .	...	...	...	Included above	Not given	332,907	73,047	22·0	+ 60,409	+1,127,675
							...	86,617	...	+ 86,617	Not given.
	Bombay, . .	220¾	...	220¼	170,880	102,575	704,132	3,494	0·5	- 22,357	Not given.
							2,559	33,913	...	+ 33,913	
Total, all Minor Works, . .		4,170½	449	2,594¼	4,482,692	3,994,380	3,913,178	646,530	16·5	+605,240	No total available.
Grand Total, all India, . .		16,026	2882½	23,696¾	13,353,069 or 20,864 square miles	23,879,607	32,040,290	1,829,741	5·74	+726,831	No Grand Total available.

† Without the lesser Minor Works, value not given.

Appendix H.

Irrigation and Navigation Works for which Capital and Revenue Accounts are kept.

Class of Work.	No. of Works.	Direct Capital Outlay to end of 1890-91.	Gross Revenue.	Working Expenses.	Net Revenue.	Irrigated Area.	Percentage Net Revenue on Capital Outlay.	Remarks.
		£*	£	£	£	Acres.		
Irrigation.								
1. Major Works—								
(*a*) Productive, . .	35	25,465,011	1,985,041	760,493	1,224,548	7,025,621	4·81	
Add on account of old Irrigation in Madras,	...	...	289,700	34,882	254,818	...	...	
Navigation.								
(*a*) Productive, . .	1	199,779	2,804	5,197	-2,393	...	...	
(*b*) Protective, . .	8	1,660,527	38,046	24,893	13,153	146,847	0·79	
2. Minor Works—								
Irrigation.								
(*a*) Works for which Capital and Revenue Accounts only are kept,	69	2,607,739	425,063	222,919	202,144	2,102,634	7·75	
Navigation, . .	7	1,687,254	68,060	50,194	17,866	...	1·06	
Totals, . . .	120	31,620,310	2,808,714	1,098,578	1,710,136	9,275,102	5·40	

* These figures should be read as tens of Rupees or Rx.

APPENDIX J

COLOUR-BLINDNESS

THE inner lining of the human eyeball is the retina. It is chiefly composed of nerve-matter whose function is to receive impressions of external objects focussed upon it, and convey them through the optic nerve to the brain. The retina is able to perceive not only the form of objects but also their colour. In mechanical arrangement the eye is very similar to a photographic camera, and the retina corresponds to the ground-glass focussing screen, on which a coloured image of the view is thrown.

The nerve fibres of the retina are really the direct prolongation of those of the optic nerve itself, and the rays of light which are focussed upon them form the stimulus which excites the sensorium at the other, or cerebral, extremity of the optic nerve.

There have been many theories expounded to account for the manner in which the retina performs its functions; but none of these hypotheses are quite satisfactory, inasmuch as they all leave some of the phenomena of vision unexplained. That which is usually accepted as being nearest to the truth, and which accounts for the majority of the facts, is known as the 'Young-Helmholtz' theory. It supposes the existence of three separate and distinct sets of nerve-fibres in close proximity to one another, and so disposed that the whole surface of the retina is well supplied by each set. Each of these three kinds of nerve-fibres is specially sensitive to one of the three primary colours—one set to violet light, one to red light, and the other to green light. But in addition to exciting its own special nerve-fibres *vividly*, each primary colour has also the power to excite each of the other sets of fibres, but *to a much less extent*. When white light (a blend of the three primary colours) enters the eye, all three sets of fibres are, of course, strongly stimulated. Suppose that one of the three sets of nerve-fibres is absent from the retina, the primary colour corresponding to that particular set cannot, *de facto*, be seen; but that primary colour will nevertheless slightly stimulate each of the

other two sets of fibres. In such a case colour-blindness for the said colour is said to exist.

Let us take as an example of this condition, a person in whose retina the fibres for *red* are wanting. This person is incapable of perceiving red in the sense that a normal eye understands it. But the fibres for violet, and those for green, will be slightly stimulated by a red ray, and so he will receive an impression resulting from the stimulation of these two sets only, and consequently a sensation of faint bluish green (a mixture of faint violet and faint green) will result.

So we see that a person who is colour-blind for any particular colour, really sees the *complement* of that colour; and moreover that the said complementary colour thus produced is much less brilliant, *cæteris paribus*, than other colours for which he is not blind.

It has been independently observed by Professor Grossman of Liverpool, by Dr. Edridge Green, and by Mr. St. Clair Buxton of London, as well as by a well-known Swiss ophthalmologist, that there are persons who may be blind for a certain colour when looking at a luminous object (as for instance a signal-lamp) who are quite able to see and recognise the same colour reflected from the surface of an opaque, non-luminous substance (such as a flag). This is an extremely rare form of colour-blindness, but its existence has been proved. Its importance is obvious in considering the proper tests to be employed in weeding out men unfit for railway service.

The usual test recommended for ascertaining if any deficiency of colour-perception is present, is that known as Holmgren's Wool Test. It consists of placing before the candidate a heap of forty or fifty skeins of Berlin wool, of various colours and shades of colour. The examiner picks out one of the skeins, and directs the candidate to match it in colour—*irrespective of shade*, with all the other skeins which at all resemble it. Should a mistake be made, the candidate is at once rejected, but should he accomplish the task satisfactorily another skein differing entirely in colour from the first is presented to him, with instructions to proceed as before. A mistake will here again reject the man. A third skein is used if the second ordeal is passed, on the same terms as the other two.

Many railway companies have hitherto been singularly lax in their methods of examining men for colour-defect. They have often satisfied themselves with directing a foreman to test the man with a so-called 'test-card.' This is merely a stout piece of

paper divided into a few squares, each of a different colour, and any man able to *name* each of the squares is considered fit for duty. It is quite easy to procure these cards, and the candidates can readily be instructed beforehand so as to give correct replies. Obviously the system is useless. Another plan much in vogue, is to take the men out on the line at night and require them to name the colour of certain signal-lights indicated. This is quite as easy a matter as the other, inasmuch as the lamps are fairly *equally illuminated*, and a man who is blind for green knows that a green lamp looks just like a red one, only much *fainter*. Even if he did not know this and simply made guesses, the chances would be equal each time that he named the right colour. Such tests as these are worse than useless, for not only do they not detect colour-blindness, but they foster a false feeling of security which by no means exists.

There is no doubt that the *principle* of the Holmgren Wool Test is the best, and this method of examining candidates should always be used, with, however, the addition of a luminous test to ferret out any cases of deficiency which may have escaped detection by means of the wools. No lantern test is of any use *unless the brilliancy of the illumination can be greatly and quickly varied*, however many pieces of coloured glass it may contain. With lanterns deficient in this feature, the examiner is placed in very similar conditions to those of the men tested by real signal-lights; a man who is conscious of his defect may often pass such tests to the complete satisfaction of the examiner. But place this man on a locomotive, let the weather be misty, the distance from the signal uncertain, and that man will be absolutely unable—perhaps in a moment of imminent peril—to decide whether the dim light before him is red or green. It has been computed that about four per cent. of the male population is colour-blind from birth, and not a few more cases are traceable to tobacco-smoking. It is therefore obvious that not only should all railway servants whose duties necessitate the recognition of signals be thoroughly tested, but also that they should be tested *frequently*.

An instrument named the 'Telechrome' has been for some time in constant use at the Admiralty, which has been found by the naval medical authorities to work admirably. This instrument, devised by Mr. St. Clair Buxton, one of the surgeons to the Western Ophthalmic Hospital, consists essentially of two parts; a lantern, in which the brilliancy of the illumination can be rapidly varied

by moving the arm of a lever, and a metal disc placed vertically in front of the lantern. The disc turns upon its axis at the pleasure of the examiner, and it carries a number of coloured glasses set in small apertures near its periphery. Light from the lantern can only pass through one of the coloured glasses at any given time, and the candidate (who has previously been tested with Holmgren's wools) is required to match a skein of Berlin wool with any similar colours he may be shown in the Telechrome, irrespective of their brilliancy. A colour-blind man who has managed to pass the Holmgren wool portion of the examination, thus finds himself confronted by a far more severe test, and one which he cannot be 'coached up' in. A faint-coloured ray from the Telechrome is more likely to be confused with its complementary colour in Berlin wool, than would two skeins of Berlin wool each complementary to the other. In using the Telechrome, therefore, the examiner shows each of the coloured rays (not in regular succession, but in irregular order) several times, and each time with different degrees of luminosity. If the candidate shows no hesitation in matching or rejecting colours when given first a red skein, then a pale green one, and finally a buff one, it may be safely taken for granted that his vision is normal.

It was stated in evidence given before the committee recently appointed by the Royal Society to inquire into the subject of colour-blindness and colour tests, that no candidate who had once failed to pass the Admiralty colour-tests, had ever succeeded in satisfying the examiners on subsequent occasions.

No test, however good in itself, can be relied on unless the skill and knowledge of the examiner are beyond question. The time and care necessary to employ any test adequately is necessarily long and great; but is of small moment compared with the serious risks to life and property which must be incurred, when men are intrusted with the charge of trains, without having been subjected to the most searching examination.

Appendix K.—Particulars of some of the large Railway Bridges in India.

Standard Gauge Railways. 5 ft. 6 in.	Name of Bridge.	No. of Spans.	Span in clear	Max. depth of founds below low-water.	Height low water to under side of Girders.	Total length of Bridge.	Total cost, including Protective Works.	Remarks.
			Feet.	Feet.	Feet.	Feet.	Rs.	
East Indian Railway.	Sone, . . .	28	150	32	35⅗	4726	43,33,324	For double line, railway above and roadway below.
	Jumna—Allahabad,	14 3	200 30	42	60	3235	44,46,300	Single line. Do.
	Jumna—Delhi, .	12	211½	39	23½	2640	16,60,355	Do.
	Jubilee—Hooghly,	2 1	524 106½	98½	55	1213¼	32,51,514*	For double line. * Includes plant and supervision.
	Approach viaducts.	141	10·83·48	...	...	3719	5,44,874	Brick arches.
Great Indian Peninsula Railway.	Kistna, . . .	36	100	9	48⅗	3855	12,73,066	Single line. Piers for double line.
	Tapti, . .	28 5	59 138	16	60⅓	2556	16,27,248	For double line.
	Nerbudda, .	5 6	137 40	4⅗	81⅓	1052	6,69,096	Single line. Piers for double line.
Bombay, Baroda, and Central India Railway.	Nerbudda, . .	25	183½	76	48½	4687½	37,75,759	Do.
	Tapti, . . .	30	60	20	50½	1875	9,02,082	Do.
Madras Railway.	Cheyer, . . .	50	64	100	14	3500	12,45,464	Does not include cost of old bridges renewed.
	Tungabhadra, .	58	64	14	34	4060	7,55,756	
	Penner, . . .	13	131	54	22	1830	11,32,077	
	Chitravati, . .	19	131	78	18	2670	13,58,194	
	Papaghni, Old, .	20	64	...	...	1410	1,62,354	
	Papaghni, New, .	15	131	62	15	2110	9,29,598*	* Approximate only.
Eastern Bengal.	Gorai, . .	7 9	185 46¼	96 25	51 46½	1744	14,83,750	
				Carry	forward,	46,882¾	295,45,811	

Large Bridges—*Continued.*

Standard Gauge Railways, 5 ft. 6 in.	Name of Bridge.	No. of Spans.	Span in clear	Max. depth of founds below low-water.	Height low-water to under side of Girders.	Total length of Bridge.	Total cost, including Protective Works.	Remarks.
			Feet.	Feet.	Feet.	Feet.	Rs.	
	Brought forward,					46,882¾	295,45,811	
Bhopal Itarsi.	Nerbudda,	14	150	4	65	2240	9,44,171	Railway and roadway on same level.
Oudh and Rohilkund Railway.	Gumti, Jaunpore,	16	82	50	44	1472	7,54,678	Railway and roadway on same level.
	Raneegunge,	34	56	85	26	2260	14,92,400	Heavy protective works.
	Ganges, Rajghat,	33	80	55	24½	3040	7,98,199	Do.
	Ganges, Cawnpore,	25 2	100 40	65	32	2830	17,46,957	Railway above and roadway below.
	Ganges, Balawali,	11	248	100	40	2904	27,72,709	Do.
	Ganges, Dufferin Bridge, Benares,	7 9	331 104	141	75⅓	3523	48,91,151	Roadway on same level as railway.
	Solani,	11	148¾	60	16	1760	10,12,473	Do.
Bengal Nagpur Railway.	Kanhan,	6 2	170 60	26	50	1237	6,72,915	Do.
	Weingunga,	9	150	21	54	1450	10,03,733	Converted from metre gauge.
	Sheonath II.,	14	150	12	57	2250	8 83,593	Do.
	Eeb,	9	150	55	38	1461	6,30,425	Approximate only.
	Damuda,	2 10	100 200	75	40¾	2364	10,25,549	Do.
Indian Midland Railway.	Chambal,	12 2	186 136	75	112½	2714	32,71,035	
	Jumna, Kalpi,	10	250	90	76⅔	2640	25,27,545	Abutments and piers for a double line.
	Betwa, Manikpur,	13 1	150 60	13	77¾	2166	13,95,181	
	Ken,	12 1	100 250	4	65⅓	1558	7,36,008	
	Betwa, Laltipur,	9	150	12	56	1446	7,64,672	
	Carry forward,					86,197¾	568,69,205	

Large Bridges—*Continued.*

Standard Gauge Railways, 5 ft. 6 in.	Name of Bridge.	No. of Spans.	Span in clear.	Max. depth of founds below low-water.	Height low-water to under side of Girders.	Total length of Bridge.	Total Cost, including Protective Works.	Remarks.
			Feet.	Feet.	Feet.	Feet.	Rs.	
	Brought forward,					86,197¾	568,69,205	
	Beas, ...	33	99	70	20	3820	25,90,166	Abutments and piers for a double line.
	Jumna, Saharanpur,	26	99	42	19	2663½	15,34,600	
	Kaiser-i-Hind, Ferozepore, Sutlej,	27	144½	78	26	4293	41,08,266	Railway below and roadway above.
	Ravi, ...	33	90	75	20	3217	16,02,315	Railway above and footway below.
	Alexandra, Chenab, .	64	133½	75	20	9088	56,56,433	
	Jhelum, ...	50	90	30	20¾	4875	17,11,872	
North Western Railway.	Attock, Indus, . .	5	2·308·4 3·257	10·12	111	1655	32,20,516	Railway above and military roadway below.
	Empress, Sutlej, Adamwahan,	16	250	103	28¾	4210	71,02,689	Railway and roadway on same level.
	Victoria, Jhelum, .	17	150	82	19	2720	19,48,811	Do.
	Lansdowne, Sukkur Indus, Rohri Channel,	1	790	...	51	900	27,89,340	Do.
	Sukkur Channel,	1 1 1	270 230 90	6	46	620	5,57,380	Do.
	Sher Shah, Chenab,	17	200	75	29	3650	28,34,101	Do.
	Total,	Standard Gauge				127,909¼	925,25,694	

24¼ Miles £9,252,560 at par of exchange.

Large Bridges—*continued.*

Metre Gauge Railways. 3 ft. 3⅜ in.	Name of Bridge.	No. of Spans.	Span in clear.	Max. depth of founds below low-water.	Height low-water to under side of Girders.	Total length of Bridge.	Total cost including Protective Works.	Remarks.
			Feet.	Feet.	Feet.	Feet.	Rs.	
Rajputana Malwa State Railway.	Jumna-Agra, . .	16	133	70	31⅔	2272	18,33,877	Railway below and roadway above.
	Nerbudda, . .	14	183	14	80	2836	18,73,925	Railway above and roadway below.
	Jumna-Mutra, . .	7	150	71	27	1146	8,49,000	Railway and roadway on same level.
Southern Mahratta Railway.	Bhima, ...	14	150	18⅔	59	2342	8,30,383	Do.
	Kistna-Byapur, .	21	150	13	43	3392	11,39,327	Do.
	Kistna-Poona, . .	14	150	4	75⅔	2339½	8,29,643	Do.
	Hagari, ...	34	64	68⅓	16⅓	2396	7,63,905	Do.
	Dorabavi, . . .	1 2 1	250 150 66½	...	179⅔	670	7,088,67	Do.
Bengal and North-Western Railway.	Rapti, ...	9	150	86	41	1445	14,29,172	Do.
Tirhoot Railway.	Gundak, ...	8	250	90	37½	2176	13,84,883	Footway on each side.
Total Metre Gauge Railways, ...						21,014½	116,42,982	= 554 Rs. per foot-average.
Total Standard Gauge Railways, ...						127,911¼	925,25,694	= 723⅓ Rs. per foot-average.
Grand Total all Railways, ...						148,925¾	1041,68,676	= 699½ Rs. per foot-average.

28¼ Miles £10,416,867 at par of exchange.

APPENDIX L.—PARTICULARS OF IMPORTANT TUNNELS ON INDIAN RAILWAYS.

Railway.	Name of Tunnel.	Single or double line.	Gauge.	Proportion lined.	Total length.	Cost, including Tools and Plant.	Material.
				Feet.	Feet.	Rs.	
GREAT INDIAN PENINSULA RAILWAY.	Thul Ghât No. 2, . .	Double	5′.6″	1625—all	1625	3,90,394	Loose rock.
	Do. No. 7, . .	Do.	Do.	...	1461	1,77,255	Rock.
	Do. No. 8, . .	Do.	Do.	...	1247	1,52,325	Rock.
	Bhore Ghât No. 13, .	Do.	Do.	..	1305	1,73,649	Hard Trap Rock.
	Do. No. 24, .	Do.	Do.	...	1023	1,50,352	Do.
SOUTHERN MAHRATTA RAILWAY.	Castle rock, . . .	Do.	5′.6″	1242—all	1242	9,08,615	Loam.
	Nandicanama, . . .	Single	Do.	1527—all	1527	4,41,418	Limestone rock.
BENGAL NAGPUR RAILWAY.	Bhortonk, ...	Do.	5′.6″	1000—all	1000	2,09,715	Hard rock, no water.
	Saranda, ...	Do.	Do.	1253—$\frac{3}{4}$ 388 unlined	1641	7,53,943	Hard Rock. *Still unfinished.
NORTH WESTERN RAILWAY.	Karez, ...	Do.	5′.6″	...	2034	4,41,963	Hard Limestone.
	Iron Gates, ...	Do.	Do.	...	1233	3,12,679	Do.
	Mud Gorge, ...	Do.	Do.	1092—$\frac{3}{4}$	1092	4,12,344	Do.
	Khojak, ...	Double	Do.	5000—$\frac{1}{2}$ 7870—$\frac{3}{4}$	12,870	65,24,872	Shale, clay, and shingle, with much water, nearly all requiring timbering.
Combined length and cost of 23 Minor Tunnels on various lines, 300′ to 900′ long, ...					16,131	39,96,467	Various.
Grand Total, ...					45,431	150,45,991	
					$8\frac{3}{4}$ Miles	£1,50,460 at par of exchange.	

APPENDIX M.—MAIN RESULTS OF WORKING ALL INDIAN RAILWAYS FOR THE YEAR ENDING 31ST DECEMBER 1891.

Details.	Standard Gauge.	Metre Gauge.	Special Gauge.	Total of all Gauges.
Open Mileage on 31st December, ... Miles,	10,047·73	6,946·68	288·31	17,282·72
Mean Mileage worked during year, ...	10,055·82	6,695·22	286·59	17,037·63
Capital Outlay on open line, including steamboat services and suspense—Rs.	1,6869,18,826	5,149,13,408	88,09,682	2,210,641,916
No. of Passengers booked, ... No.	80,335,272	41,596,189	923,876	122,855,337
No. of Passengers booked per mean mile worked, . . .	7,989	6,213	3,224	7,211
No. of tons of Goods moved, ... Tons,	19,343,709	6,652,013	163,231	26,158,953
No. of tons of Goods moved per mean mile worked, . . .	1,924	994	570	1,535
Passenger unit miles, ... Unit miles,	3,561,612,772	1,641,930,653	22,564,548	5,226,107,973
Ton mileage of Goods, ... Ton miles,	3,589,116,058	845,567,526	4,308,847	4,438,992,431
Train Miles, ... Miles,	42,047,302	18,257,923	494,940	60,800,165

APPENDIX M.—MAIN RESULTS OF WORKING ALL INDIAN RAILWAYS FOR THE YEAR ENDING 31ST DECEMBER 1891.

Details.		Standard Gauge.	Metre Gauge.	Special Gauge.	Total of all Gauges.
Gross Earnings—Coaching,	Rs.	552,25,243	216,93,010	6,19,367	775,37,620
" Goods,	"	1,240,28,024	313,59,858	6,93,304	1,560,81,166
" Steamboat, Telegraph, and Miscellaneous,	"	48,08,465	19,58,026	1,7,513	67,84,004
Total,	"	1,840,61,732	550,10,874	13,30,184	2,404,02,790
Gross Earnings per mean mile worked,	"	18,304·00	8,216·44	4641·42	14,110,11
Working Expenses—Maintenance,	"	232,65,868	75,30,981	1,98,783	309,95632
" Locomotive,	"	277,72,861	97,83,966	2,71,849	378,28,676
" Carriage and Wagon,	"	80,18,041	23,11,739	80,889	104,10,669
" Traffic,	"	126,59,477	44,34,979	1,47,406	172,41,862
" General,	"	74,49,011	38,13,184	1,29,387	113,90,224
" Steamboat—Special and Miscellaneous,	"	39,38,543	12,07,401	24,106	51,71,408
Total,	"	831,03,801	290,82,250	8,52,420	1,130,38,471
Working Expenses per mean mile worked,	"	8,264·25	4,343·73	2,974·35	6,634·64
Percentage of Working Expenses to gross earnings,		45·15	52·87	64·08	47·02
Net Earnings,	"	1,009,57,931	259,28,624	4,77,764	1,273,64,319
Percentage of net earnings on total Capital on open line, including suspense,		5·98	5·04	5·42	5·76

Appendix N.

Statement showing the Quantity in Tons of Coal produced in India during the last twelve years.

Years.	Bengal.	Punjab.	Central Provinces.	Assam.	Central India.	Nizam's Territory.	Madras.	Baluchistan.	Total.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons	Tons.	Tons.
1880	988,565	...	31,228	...	...	...	...	...	1,019,793
1881	930,203	...	67,527	...	...	...	...	...	997,730
1882	1,038,872	...	91,370	...	...	...	...	...	1,130,242
1883	1,200,957	...	115,019	...	...	...	...	...	1,315,976
1884	1,257,392	...	121,833	16,493	2,100	...	...	...	1,397,818
1885	1,123,700	...	119,116	43,707	7,698	...	...	...	1,294,221
1886	1,186,802	...	117,287	70,859	13,539	...	...	...	1,388,487
1887	1,319,090	7,523	128,981	89,302	15,497	3,259	...	411	1,564,063
1888	1,380,594	11,249	157,768	101,528	41,580	13,382	...	2,802	1,708,903
1889	1,541,356	22,835	144,465	116,676	52,956	59,646	...	7,420	1,945,354
1890	1,626,245	40,677	137,022	145,708	77,842	125,486	...	15,541	2,168,521
1891	1,537,175*	60,714	141,736	154,208	69,741	144,668	70	10,368	2,118,680
Totals,	15,130,951	142,998	1,373,352	738,481	280,953	346,341	70	36,542	18,049,688

* All returns not received.

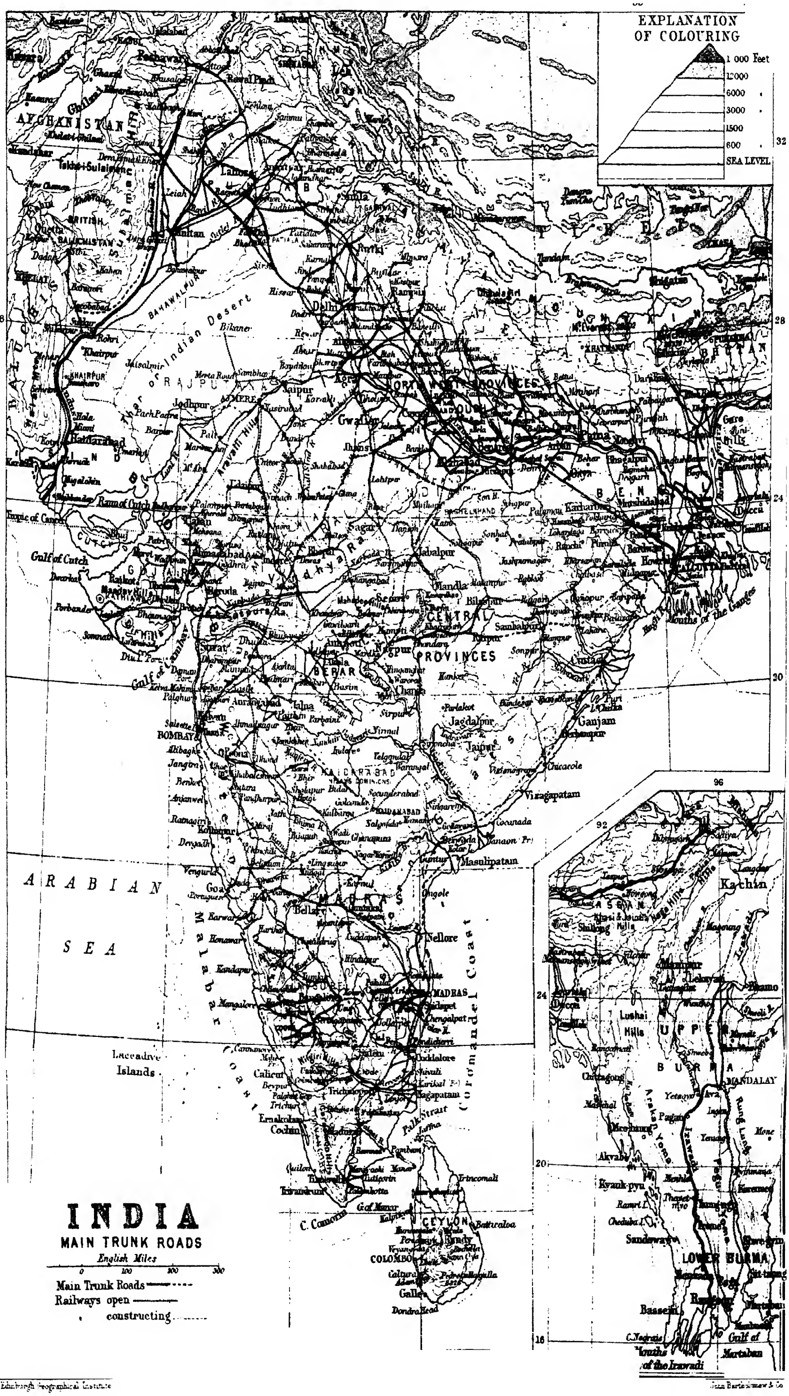
INDEX

INDEX

THE END

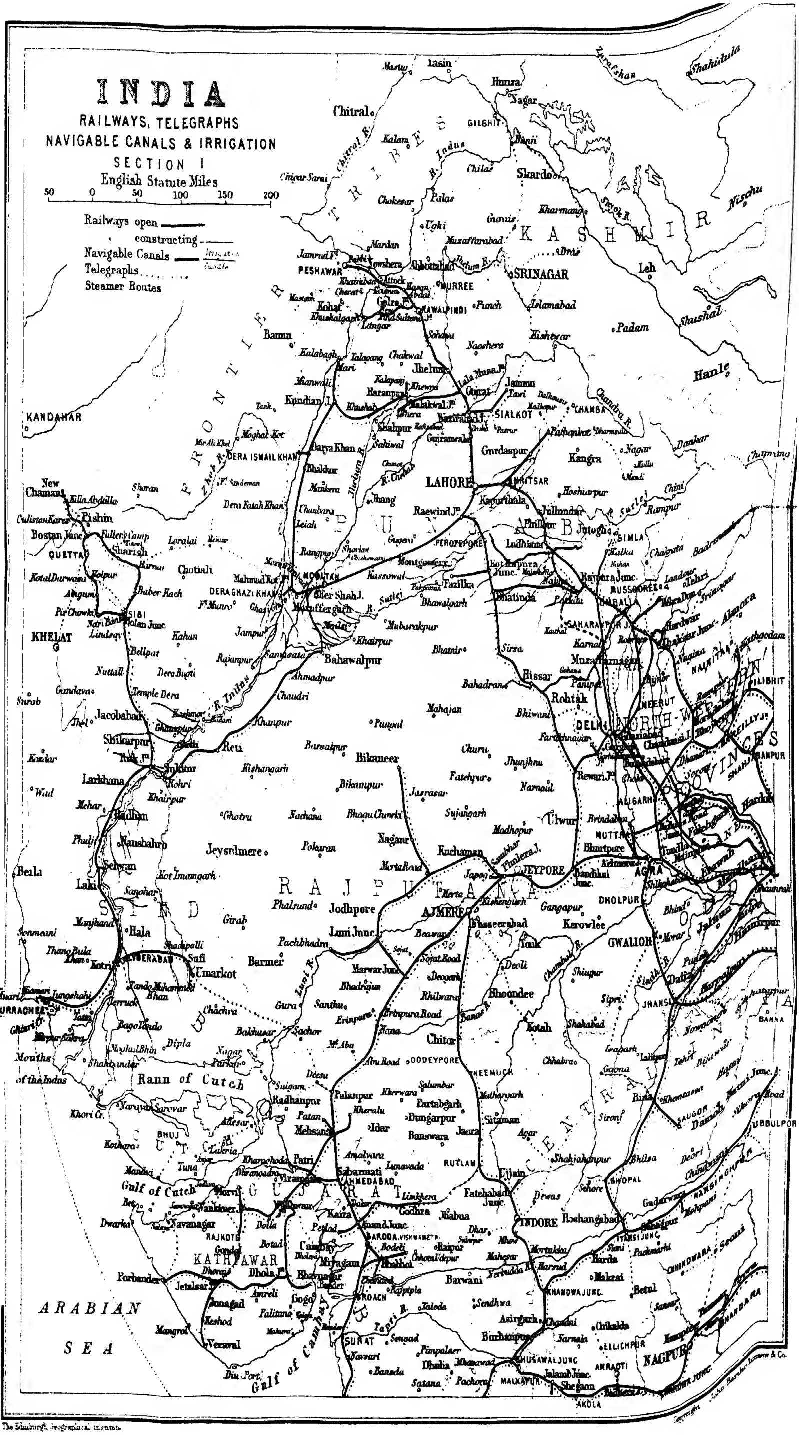
Printed by T. and A. CONSTABLE, Printers to Her Majesty
at the Edinburgh University Press.

Plate 1.

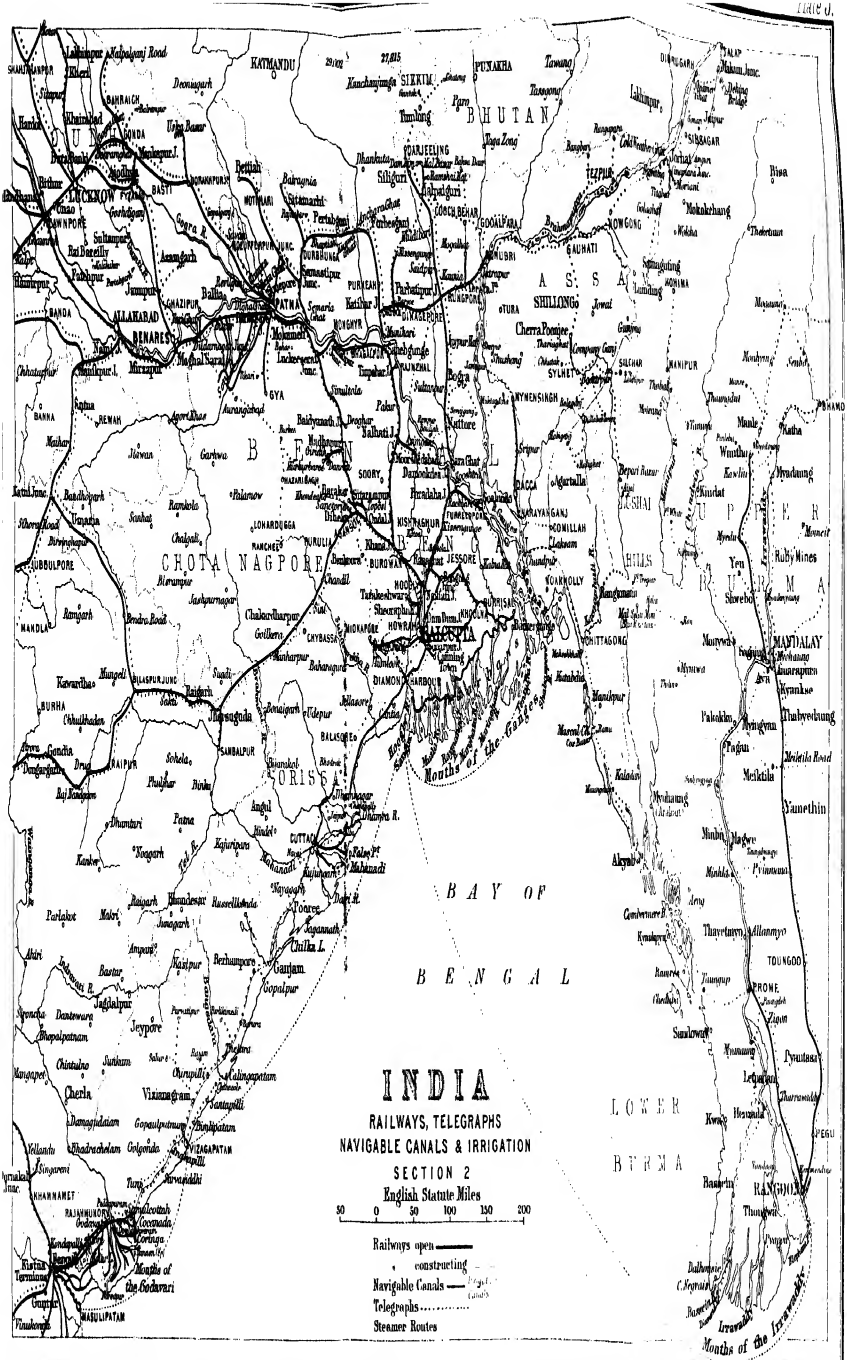


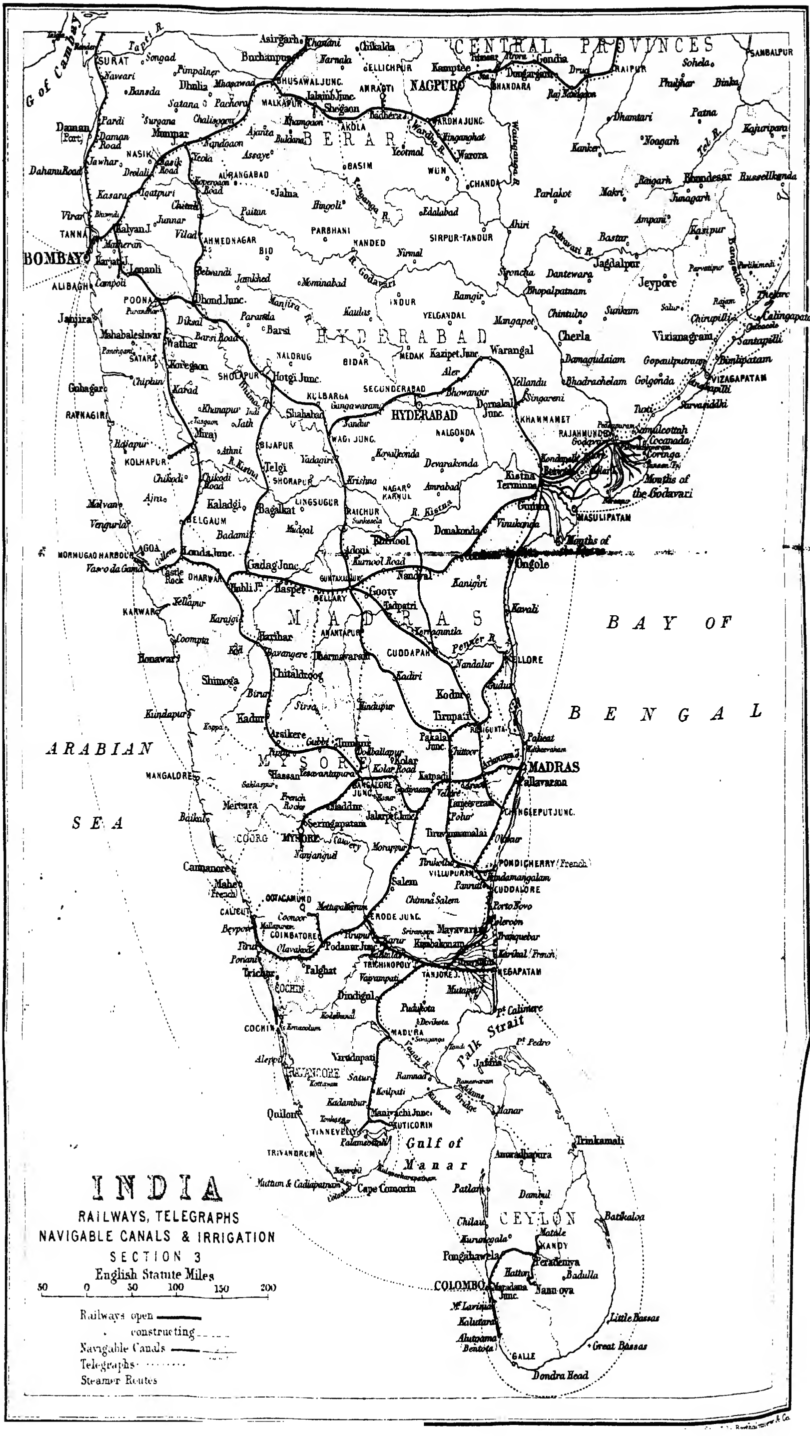
The Edinburgh Geographical Institute

John Bartholomew & Co.



The Edinburgh Geographical Institute


INDIA
RAILWAYS, TELEGRAPHS
NAVIGABLE CANALS & IRRIGATION
SECTION 2
English Statute Miles
50 0 50 100 150 200
Railways open
constructing
Navigable Canals
Telegraphs
Steamer Routes
BAY OF
BENGAL
LOWER
BURMA
BHUTAN
ASSAM
CHOTA NAGPORE
ORISSA
UPPER BURMA
LUCKNOW
ALLAHABAD
BENARES
PATNA
CALCUTTA
DACCA
CHITTAGONG
MANDALAY
RANGOON
CUTTACK
VIZAGAPATAM
KATMANDU
Mouths of the Ganges
Mouths of the Irrawaddy
Mouths of the Godavari


INDIA
RAILWAYS, TELEGRAPHS
NAVIGABLE CANALS & IRRIGATION
SECTION 3
English Statute Miles
50 0 50 100 150 200
Railways open
constructing
Navigable Canals
Telegraphs
Steamer Routes
CENTRAL PROVINCES
BERAR
HYDERABAD
MADRAS
MYSORE
CEYLON
ARABIAN SEA
BAY OF BENGAL
G of Cambay
Palk Strait
Gulf of Manar
BOMBAY
POONA
NAGPUR
HYDERABAD
SECUNDERABAD
MADRAS
BANGALORE
MYSORE
COCHIN
TRIVANDRUM
Cape Comorin
COLOMBO
KANDY
GALLE
Dondra Head
MANGALORE
GOA
MORMUGAO HARBOUR
SURAT
NASIK
KOLHAPUR
BELGAUM
DHARWAR
BELLARY
CUDDAPAH
NELLORE
Ongole
MASULIPATAM
VIZAGAPATAM
Vizianagram
Calingapatam
RAJAHMUNDRY
Cocanada
Mouths of the Godavari
TRICHINOPOLY
TANJORE J.
NEGAPATAM
MADURA
TUTICORIN
Jaffna
Trinkamali
Batikaloa
PONDICHERRY (French)
CUDDALORE
Salem
OOTACAMUND
COIMBATORE
CALICUT
Cannanore
Quilon
Alleppy
Raipur
SAMBALPUR
Jeypore
Jagdalpur
Warangal
KHAMMAMET
Kurnool
Guntakal
Hubli Jn.
Gadag Junc.
SHOLAPUR
Hotgi Junc.
Wardha Junc.
CHANDA
AKOLA
AURANGABAD
AHMEDNAGAR
Dhond Junc.
Kalyan J.
TANNA
Daman (Port.)
Mahe (French)
Karikal (French)

The Commerce and Navigation of the Erythraean Sea

Being a Translation of the 'Periplus Maris Erythraei,' and of Arrian's Account of the Voyage of Nearkhos. *8vo.* 5*s. net.*

Ancient India as Described by Ktesias the Knidian

8vo. 4*s.* 6*d. net.*

Ancient India as Described by Ptolemy

With an Introduction and a Map of India according to Ptolemy. *8vo.* 5*s. net.*

The Rival Powers in Central Asia

Translated from the German of JOSEPH POPOWSKI by ARTHUR BARING BRABANT, and edited by CHAS. E. D. BLACK. With a large Map of the Pamir Region. *Demy 8vo, Map in Pocket.* 12*s.* 6*d.*

The Ruling Races of Prehistoric Times in India

By J. F. HEWITT. With a Map. *Demy 8vo.*

*** This work traces all forms of National Government to the primæval Village Communities of the forest races of Southern India; and shows how these Southern farmers and the Northern hunting and pastoral tribes and fire-worshipping handicraftsmen met in Asia Minor, the second cradle of the civilised races. It derives their history up to their union, and afterwards, when they dispersed through Europe and Asia as corn and fruit growers, from tribal and local customs and institutions, religious and historical myths, ritualistic observances and symbols and linguistic changes, and shows the great historical importance of local botany and zoology in indicating the story of the rise to power and rule of the imperial races of the early world, the Kushika and Maghadas of India and the Semite Kushites who made Assyria and Egypt the centres of civilisation.

The Original Inhabitants of India

By GUSTAV OPPERT, PH.D., Professor of Sanscrit in the University of Madras.

*** The main object of the work is to prove from existing sources that the original inhabitants of India, with the exception of a small minority of foreign immigrants, belong all to one and the same race, branches of which are spread over the Continents of Europe and Asia, and which is also known as Finnish-Ugrian or Turanian. *Demy 8vo, cloth,* 20*s.* *A few copies on large paper,* £2.

Burma a Hundred Years Ago

As described by FATHER SANGERMANO. Edited with Notes and Introduction by the Hon. Mr. JUSTICE JARDINE. With a Map. *Demy 8vo.* 10*s.* 6*d.*

A Monograph on the Coins of the Hindu States of Rajputana

By SURGEON-CAPTAIN W. W. WEBB.

With twelve Plates and a Map in colours showing the Mint towns in Rajputana. *Royal 8vo, cloth gilt,* 16*s. net.*

'The drawings are well reproduced, and are admirably illustrative of the book.'—*Saturday Review.*

'So far as we know, this is the first book that has been published about the coins of the Native States in India.'—*Academy.*

'Dr. Wilfrid Webb has written a scholarly and admirably illustrated monograph.'—*Speaker.*